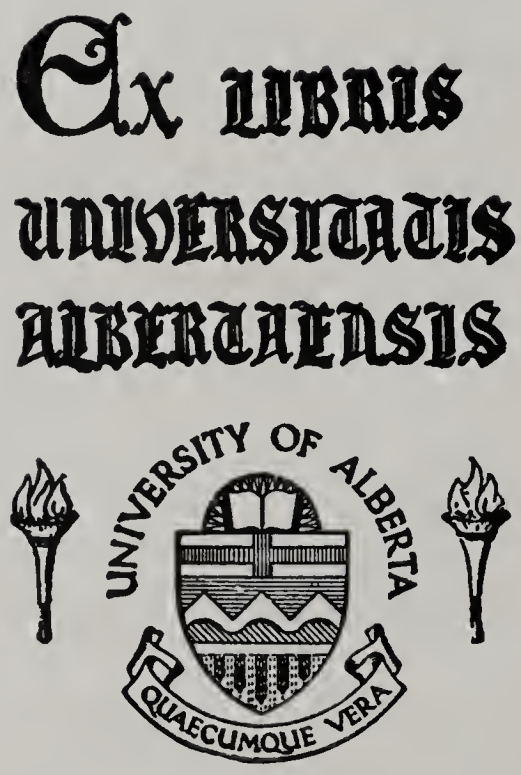

University of Alberta
Printing Department

THESIS

THE EFFECT
OF
REPETITIVE TETANIC STIMULATION
ON
MUSCLE STRENGTH AND FATIGUE
IN
HEALTHY SUBJECTS

Submitted to the faculty of graduate studies of the University of Alberta in partial fulfilment of the requirements for

THE DEGREE OF MASTER OF SCIENCE

FACULTY OF PHYSICAL EDUCATION

BY

Victor R. Messier
EDMONTON, Alberta.
August, 1965.

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

THE UNDERSIGNED CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES FOR ACCEPTANCE, A THESIS ENTITLED.....

"THE EFFECT OF REPETITIVE TETANIC STIMULATION ON MUSCLE STRENGTH AND FATIGUE IN HEALTHY SUBJECTS"

SUBMITTED BY VICTOR R. MESSIER IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN PHYSICAL EDUCATION.

ABSTRACT

THE MAIN PURPOSE OF THIS STUDY WAS TO INVESTIGATE THE EFFECTS OF REPETITIVE, ELECTRICAL, TETANIC STIMULATION ON THE STRENGTH AND FATIGUE OF THE ULNAR INNERVATED MUSCLES OF THE NON-DOMINANT HAND IN HEALTHY ADULTS. TEN MALES AND EIGHT FEMALES VOLUNTEERED TO PARTICIPATE IN THE EXPERIMENT. THEY WERE DIVIDED INTO THREE GROUPS: A (N = 9) UNDERWENT A DAILY, SIX SECOND, TETANIC CONTRACTION; V (N= 5) EXERCISED BY DOING A DAILY, SIX SECOND, MAXIMUM, VOLUNTARY, ISOMETRIC CONTRACTION, AND C (N = 4) ACTED AS A CONTROL GROUP AND THEY CARRIED ON THEIR NORMAL EVERYDAY ACTIVITY. THE ULNAR INNERVATED MUSCLES OF THE DOMINANT HAND AS WELL AS THE NON-DOMINANT HAND OF ALL THE SUBJECTS WERE MEASURED FOR THE FOLLOWING PARAMETERS: (1) GRIP TENSION, (2) TETANIC TENSION, (3) MERTON'S TENSION, AND (4) FATIGUE-TENSION RATIO. THE MEASURES TAKEN ON THE DOMINANT HAND ACTED AS AN ADDITIONAL CONTROL GROUP.

THE SUBJECTS THAT UNDERWENT ELECTRICAL STIMULATION (GROUP A) SHOWED SIGNIFICANT INCREASES IN TWO OF THE FOUR MEASURES - GRIP TENSION AND TETANIC TENSION. GROUP V SUBJECTS, WHO UNDERWENT VOLUNTARY ISOMETRIC EXERCISE, DID NOT DEMONSTRATE STATISTICALLY SIGNIFICANT GAINS IN ANY OF THE FOUR PARAMETERS UNDER DISCUSSION.

CURRENT THEORIES OF STRENGTH DEVELOPMENT ARE DISCUSSED IN THE LIGHT OF THESE FINDINGS.

TABLE OF CONTENTS

PAGE

INTRODUCTION

MAN HAS ASSOCIATED AN INCREASE IN MUSCLE STRENGTH WITH EXERCISE SINCE AT LEAST THE 6TH CENTURY B.C. AT THAT TIME MILO OF CROTONA ADVOCATED LIFTING A BABY CALF ON TO ONE'S SHOULDERS DAILY, AS A MEANS OF INCREASING MUSCULAR STRENGTH (6). AS THE CALF INCREASED IN WEIGHT SO THE INDIVIDUAL WOULD INCREASE IN STRENGTH, UNTIL HE REACHED THE LIMITS OF HIS POTENTIAL STRENGTH AT WHICH TIME HE WOULD BE UNABLE TO LIFT THE CALF.

ALL SUBSEQUENT PROGRAMS TO INCREASE MUSCULAR STRENGTH WHICH HAVE PROVED EFFECTIVE HAVE THE SAME BASIC PRINCIPLE. TODAY THIS IS KNOWN AS THE "OVERLOAD PRINCIPLE". IN ESSENCE THE "OVERLOAD PRINCIPLE" STATES THAT TO INCREASE THE STRENGTH OF A GIVEN MUSCLE, AN INCREASING AMOUNT OF TENSION HAS TO BE PRODUCED BY THAT MUSCLE FOR A CERTAIN PERIOD OF TIME AND AT CERTAIN REGULAR INTERVALS.

THE QUESTIONS OF HOW MUCH, HOW LONG, AND HOW OFTEN THIS TENSION HAS TO BE EXERTED TO BRING ABOUT MAXIMUM INCREASE IN MUSCLE STRENGTH ARE STILL BEING DEBATED BECAUSE ALL BUT A FEW OF THE MANY STUDIES IN THE AREA OF STRENGTH DEVELOPMENT HAVE BEEN CONCERNED WITH VOLITIONAL EXERCISE. A VARIETY OF PSYCHOLOGICAL FACTORS SUCH AS MOTOR LEARNING, ATTITUDES, MOTIVATION, FEELINGS OF WELL-BEING OR DISCOMFORT, ALL AFFECT THE AMOUNT OF EFFORT AN INDIVIDUAL WILL PUT INTO A VOLUNTARY EXERCISE. THIS EFFORT, IN TURN, WILL DETERMINE THE AMOUNT OF TENSION PRODUCED BY ANY GIVEN MUSCLE. THESE FACTORS ARE IMPORTANT WHEN MAKING A COMPARISON OF THE EFFICACY OF VARIOUS EXERCISE PROGRAMS DESIGNED TO INCREASE MUSCULAR STRENGTH. THE COMMENTS OF IKAI AND STEINHAUS ARE REPRESENTATIVE OF THE OPINIONS HELD BY A NUMBER OF INVESTIGATORS IN THE FIELD OF STRENGTH DEVELOPMENT.

> "OUR FINDINGS APPEAR TO SUPPORT THE THESIS THAT IN EVERY VOLUNTARILY EXECUTED, ALL-OUT MAXIMAL EFFORT, PSYCHOLOGIC RATHER THAN PHYSIOLOGIC FACTORS DETERMINE THE LIMITS OF PERFORMANCE. BECAUSE SUCH PSYCHOLOGIC FACTORS (INCLUDING PHARMACOLOGICALLY INDUCED PSYCHIC STATES) ARE READILY MODIFIED, THE IMPLICATIONS OF THIS POSITION GRAVELY CHALLENGE ALL ESTIMATES OF FITNESS AND TRAINING EFFECTS BASED ON TESTING PROGRAMS THAT INVOLVE MEASURES OF ALL-OUT OR MAXIMAL PERFORMANCE." (15:161)

BECAUSE PSYCHOLOGICAL FACTORS ARE MANY, VARIABLE, AND DIFFICULT TO CONTROL, IT WAS THOUGHT THAT IT WOULD BE VALUABLE TO REVIEW STUDIES OF THE EFFECT OF TENSION ON MUSCLE STRENGTH WHERE THESE FACTORS ARE EITHER ELIMINATED COMPLETELY OR ARE INSIGNIFICANT. SUCH FACTORS CAN BE MINIMIZED, AND PROBABLY EXCLUDED BY ELECTRICAL STIMULATION OF THE LOWER MOTOR NEURON. FOR THIS REASON IT WAS DECIDED TO FOCUS OUR REVIEW ON THOSE STUDIES CONCERNED WITH ARTIFICIAL EXERCISE BY MEANS OF ELECTRICAL STIMULATION.

A. REVIEW OF LITERATURE

AT THE TURN OF THE CENTURY TWO INVESTIGATORS NOTED THE EFFECTS OF ARTIFICIAL STIMULATION ON THE STRENGTH OF HEALTHY MUSCLE IN ANIMALS. DEBEDAT IN 1894 AND BORDIER IN 1902 REPORTED THAT AFTER DAILY TREATMENT WITH STRONG ELECTRICAL CURRENTS MARKED INCREASES IN WEIGHT AND POWER WERE OBSERVED IN HEALTHY MUSCLE IN RATS.

NOWAKAWSKA IN 1962 INVESTIGATED THE EFFECTS OF TRAINING BY MEANS OF ELECTRICAL STIMULATION UPON THE EXCITABILITY AND WORK CAPACITY OF NORMALLY INNERVATED MUSCLES OF THE RIGHT REAR EXTREMITY OF RATS. AFTER 35 DAYS ON THIS PROGRAM, HE CONCLUDED THAT THE TREATED LIMB DEFINITELY INCREASED IN EXCITABILITY AND IN WORK CAPACITY AS INDICATED BY THE ABILITY OF THE MUSCLES TO LIFT A 100 GRAM WEIGHT SUSPENDED FROM THE ACHILLES TENDON STIMULATED AT A FREQUENCY OF 100 PER MINUTE.

A DETAILED REVIEW OF THE LITERATURE SHOWED ONLY ONE STUDY CONCERNED WITH THE EFFECTS OF REPETITIVE ELECTRICAL STIMULATION ON THE STRENGTH OF HEALTHY HUMAN MUSCLE. MASSEY ET AL COMPARED THE EFFECTS OF PHASIC, STATIC AND HIGH FREQUENCY ELECTRICAL STIMULATION ON THE DEVELOPMENT OF STRENGTH AND MUSCLE GIRTH. THE MEASUREMENTS TAKEN ON 47 MARINES PRIOR TO AND FOLLOWING THE TRAINING PROGRAM INCLUDED: RIGHT AND LEFT UPPER AND LOWER ARM GIRTH, RIGHT AND LEFT GRIP STRENGTH, AND RIGHT AND LEFT ELBOW FLEXION AND EXTENSION STRENGTHS. THE RESULTS SHOWED STATISTICALLY SIGNIFICANT IMPROVEMENTS FOR ALL STRENGTH AND GIRTH MEASURES FOR THE PHASIC AND STATIC GROUPS AS COMPARED TO THE CONTROL GROUP. THE

GROUP THAT UNDERWENT ELECTRICAL STIMULATION DEMONSTRATED STATISTICALLY SIGNIFICANT IMPROVEMENTS OVER THE CONTROLS IN EXTENSION STRENGTH AND IN TWO OF THE FOUR GIRTH MEASUREMENTS. THE WRITERS REPORT THAT THE DATA INDICATES THAT THE METHOD OF ELECTRICAL STIMULATION EMPLOYED IN THIS STUDY WAS NOT AS EFFECTIVE AS PHASIC OR STATIC TRAINING.

B. REASONS FOR THE PRESENT STUDY

A METICULOUS AND CAREFUL SEARCH FAILED TO REVEAL ANY OTHER STUDIES CONCERNED WITH ARTIFICIAL EXERCISE IN HEALTHY ANIMAL OR HUMAN MUSCLE. BECAUSE OF THE PAUCITY OF THE STUDIES IN THIS IMPORTANT AREA OF ARTIFICIAL EXERCISE AND STRENGTH DEVELOPMENT, IT WAS DECIDED A NEW AND MORE SPECIFIC STUDY SHOULD BE UNDERTAKEN.

THE METHOD OF ELECTRICAL STIMULATION VIRTUALLY EXCLUDES THE VOLITIONAL COMPONENT OF STRENGTH, AND HENCE AN OBJECTIVE MEASUREMENT CAN BE MADE OF THE MAXIMUM TENSION* THAT CAN BE PRODUCED BY A SPECIFIC MUSCLE. BY USING SUCH A TECHNIQUE IT SHOULD BE POSSIBLE TO ACCURATELY DETERMINE IF AN EXERCISE PROGRAM CONSISTING ENTIRELY OF ARTIFICIAL STIMULATION RESULTS IN A CHANGE IN THE TETANIC TENSION OF A MUSCLE. IT WAS DECIDED TO PRODUCE THE ARTIFICIAL EXERCISE BY DAILY TETANIC ELECTRICAL STIMULATION OF THE ULNAR NERVE AND RECORD ANY ENSUING CHANGES IN TENSION OF THE ULNAR INNERVATED MUSCLES OF THE THUMB.

IN ADDITION TO THE MAIN PROBLEM OF INVESTIGATING THE EFFECTS OF REPETITIVE ELECTRICAL STIMULATION ON THE STRENGTH OF HEALTHY MUSCLES, IT WAS THOUGHT THAT THIS STUDY COULD PROVIDE NEW INFORMATION ON MUSCLE FATIGUE. THE RELATIONSHIP OF MUSCLE FATIGUE TO MUSCLE STRENGTH IS POORLY UNDERSTOOD. ONE OF THE MAJOR REASONS FOR THIS UNCERTAINTY IS THAT THE VARIOUS PSYCHOLOGICAL FACTORS PREVIOUSLY DISCUSSED PLAY AN EVEN MORE INFLUENTIAL ROLE IN HUMAN PERFORMANCE WHEN THE PHYSICAL ACTIVITY UNDER CONSIDERATION IS CARRIED ON UNTIL EXHAUSTION ENSUES.

* MAXIMUM TENSION HERE INDICATES THE MAXIMUM TENSION PRODUCED BY ULNAR INNERVATED MUSCLES ATTACHED TO THE THUMB WHEN THE ULNAR NERVE IS STIMULATED SUPRAMAXIMALLY AT THE WRIST AT A RATE OF 50 CYCLES PER SECOND.

HOWEVER, WITH THE SPECIAL APPARATUS AND THE METHOD OF STIMULATION EMPLOYED IN THIS EXPERIMENT, THE ENTIRE FATIGUE CURVE OF THE ULNAR INNERVATED MUSCLES OF THE THUMB MAY BE OBTAINED WITH ARTIFICIAL STIMULATION IN THE HUMAN SUBJECT. UNDER THE CONDITIONS OF THIS EXPERIMENT THIS CURVE REPRESENTS THE PHYSIOLOGICAL LIMITS OF THE MUSCLE BEING INVESTIGATED. IT WAS THEREFORE DECIDED TO DETERMINE WHETHER REPETITIVE TETANIC STIMULATION AFFECTED THE RATE OF FATIGUE OF THE MUSCLE (FATIGUE-TENSION RATIO*).

IT WAS THOUGHT THAT THIS FATIGUE-TENSION RATIO WOULD PROVIDE A STABLE BASE LINE FROM WHICH THE RELATIONSHIP OF MAXIMUM TETANUS TENSION AND RATE OF FATIGUE COULD BE DETERMINED.

DESPITE THE EXPERIMENTAL LIMITATIONS OF TESTING ONLY A FEW SMALL MUSCLES AND OF MEASURING A VERY SPECIFIC TYPE OF MUSCLE STRENGTH AND FATIGUE, IT WAS FELT THAT THE RESULTS OF SUCH A STUDY WOULD BE OF CONSIDERABLE VALUE IN THE CRITICAL APPRAISAL OF MUSCLE STRENGTHENING PROGRAMS AND ALSO IN THE EVALUATION OF NEUROMUSCULAR FATIGUE.

IN SUMMARY, THE PRESENT STUDY WAS CONDUCTED TO DETERMINE IF A DAILY TETANIC NERVE STIMULATION WOULD EFFECT A CHANGE IN MUSCLE TENSION AND THE RATE OF MUSCLE FATIGUE.

* FATIGUE-TENSION RATIO IS THE TETANUS TENSION AFTER A GIVEN PERIOD OF CONTINUOUS STIMULATION AT A CERTAIN FREQUENCY DIVIDED BY THE MAXIMUM TETANUS TENSION ON INITIAL STIMULATION AT THE SAME FREQUENCY.

II

METHODS AND PROCEDURE

A. General

B. Apparatus and Procedure

C. Subjects

D. Location and Duration of Experiment

E. Test Procedure

CHAPTER II

METHODS AND PROCEDURE

A. GENERAL

IN ESSENCE THIS STUDY WAS CONCERNED WITH DETERMINING THE CHANGES THAT OCCURRED IN THE TETANIC TENSION OF THE THUMB AFTER TWO DIFFERENT EXERCISE PROGRAMS.

THE TECHNIQUE USED IN THIS STUDY FOR STIMULATING THE ULNAR NERVE AND RECORDING EVOKED POTENTIALS AND MUSCLE TENSION FROM THE THUMB WAS SIMILAR TO THAT DESCRIBED BY MERTON.

THE EXPERIMENTAL LAY OUT FOR EACH INDIVIDUAL SUBJECT IS SHOWN IN FIGS. 1 AND 2. THE SUBJECT LIES SUPINE ON A BED WITH HIS HAND SECURELY FIXED TO THE CENTRE OF A BALL BEARING RACE. THE THUMB IS HELD IN AN EXTENDED AND ABDUCTED POSITION BY A METAL SLEEVE WHICH IS ATTACHED TO A MECHANO-ELECTRIC TRANSDUCER FIXED ON THE OUTER RING OF THE RACE. THIS TRANSMITS TENSION FROM THE THUMB VIA A STRAIN GAUGE AMPLIFIER TO BE DISPLAYED ON AN OSCILLOSCOPE AND OSCILLOGRAPH. SURFACE ELECTRODES ARE PLACED OVER THE MOTOR POINT OF THE ADDUCTOR POLLICIS MUSCLE AND PASS VIA A PREAMPLIFIER TO A SECOND CHANNEL ON THE OSCILLOSCOPE IN ORDER TO DISPLAY THE ACTION POTENTIAL OF THE MUSCLES.

STIMULATING ELECTRODES ARE FIXED ON THE SKIN OVER THE ULNAR NERVE AND CONNECTED TO A SQUARE WAVE STIMULATOR.

EACH DAY ONE GROUP OF SUBJECTS (A) HAD ARTIFICIAL EXERCISE BY MEANS OF A SIX SECOND SUSTAINED TETANIC STIMULATION OF THE ULNAR NERVE WITH THE THUMB FIXED AS DESCRIBED. A SECOND GROUP (V) EXERTED A MAXIMUM VOLUNTARY ISOMETRIC CONTRACTION IN A THUMB AND HAND GRIPPING ACTION. A THIRD GROUP (C) UNDERWENT NO SPECIAL EXERCISE PROGRAM BUT WAS TESTED AT THE BEGINNING AND END OF THE FIVE WEEK TESTING PERIOD, AND ACTED AS A CONTROL GROUP.

THE TENSION OF THE MUSCLE WAS RECORDED FIVE DAYS PER WEEK FOR FIVE WEEKS DURING THE EXPERIMENT AND A COMPARISON OF MUSCLE TENSION AND RATE OF FATIGUE ON

THE FIRST AND LAST DAY OF THE EXPERIMENT WAS MADE.

DETAILED DESCRIPTION OF BOTH APPARATUS AND PROCEDURE FOLLOWS.

B. APPARATUS AND PROCEDURE

THE SAME APPARATUS WAS USED FOR BOTH THE TESTING AND THE TRAINING PROGRAM.

1. MECHANICAL - FIXATION OF HAND IN BALL BEARING RACE. THE HAND WAS PLACED IN A SPLINT CENTERED IN A BALL BEARING RACE AS SHOWN IN FIG. 2. THE SPLINT, WHICH CONSISTED OF A PLASTER-OF-PARIS MOULD OF THE DORSAL ONE-HALF OF THE FOREARM AND HAND, WAS HOUSED IN A PLYWOOD FRAME. IN ORDER TO STABILIZE THE HAND WHILE IT WAS BEING EXERCISED, A STRAP WAS PLACED AROUND THE FOREARM; A PADDED WOODEN PLATE WAS CLAMPED WITH SCREWS ACROSS THE FRONT OF THE WRIST, AND A RUBBER GRIP, THE SHAPE OF THE INSIDE OF THE CLENCHED HAND WHICH WAS MOULDED AROUND A STEEL BAR, WAS CLAMPED ACROSS THE PALMAR SURFACE OF THE HAND. THE PROXIMAL PHALANX OF THE THUMB WAS PLACED IN A SMALL METAL SLEEVE WHICH WAS CONNECTED BY A WIRE ROD TO A FLAT METAL PLATE. THIS PLATE WAS INSERTED IN A SLOT AT THE END OF A BAR ON WHICH THE STRAIN GAUGE WAS MOUNTED. A STEEL PIN WAS INSERTED INTO ONE OF MANY HOLES IN THE PLATE, SO THAT, AS THE THUMB PULLED ON THE PLATE, TENSION WOULD BE TRANSMITTED TO THE BAR AND THE STRAIN GAUGE.

THE STRAIN GAUGE BAR WAS MOUNTED ON THE OUTER RING OF THE BALL BEARING RACE, WHILE THE SPLINT SUPPORTING THE HAND WAS FIXED TO AN ALUMINUM PLATE ATTACHED TO THE INNER TRACK OF THE RACE, AND SO PLACED THAT IT WAS SLIGHTLY BEHIND THE CENTRE AND VERTICAL TO THE PLANE OF THE RACE.

THE BALL BEARING RACE (FIGS. 3 AND 4) WAS MADE OF MILD STEEL ONE-HALF INCH THICK. THE INTERNAL DIAMETER OF THE RACE WAS EIGHT INCHES, THE EXTERNAL DIAMETER FOURTEEN AND ONE-HALF INCHES AND THE OUTER TRACK OF THE RACE WAS TWO AND ONE-QUARTER INCHES WIDE. A STEEL ROD, ONE INCH IN DIAMETER, WAS RIGIDLY FIXED TO THE INNER TRACK. THIS ROD WAS INSERTED INTO A FULL SLEEVE WHICH WAS FIRMLY BOLTED TO THE FRAME OF THE BED. IN ADDITION TO PROVIDING FOR A VERTICAL ADJUSTMENT OF THE RACE, THIS ARRANGEMENT MADE THE INNER PORTION OF THE RACE STATIONARY. HENCE, THE OUTER TRACK WHICH CARRIED THE STRAIN GAUGE COULD TURN FREELY TO THE LEFT OR

RIGHT OF ANY DESIGNATED POINT ON THE INNER TRACK. THE UPPER SURFACE OF THE INNER TRACK WAS MARKED OUT IN DEGREES SO THAT WHILE THE TETANUS TENSION WAS BEING RECORDED THE EXACT POSITION OF THE THUMB COULD BE NOTED.

THE ALUMINUM PLATE WHICH HELD THE SPLINT WAS ATTACHED TO THE STEEL ROD, AND BY MEANS OF TWO ALLEN SCREWS A FINE VERTICAL ADJUSTMENT COULD BE MADE TO THE SPLINT.

2. MECHANO-ELECTRIC TRANSDUCER. THIS CONSISTS, IN PART, OF A COLD ROLLED STEEL BAR, ONE-EIGHTH OF AN INCH THICK, FIVE-EIGHTHS OF AN INCH WIDE, AND TWO AND FIVE-EIGHTHS INCHES IN LENGTH, WHICH IS FASTENED TO A BRASS RING IN SUCH A MANNER THAT THE SUBJECT IS ABLE TO APPLY TENSION TO THE TOP END OF THE STEEL PLATE THROUGH A NINETY DEGREE ANGLE.

THE ELECTRICAL PORTION OF THE TRANSDUCER EMPLOYS A FULL BRIDGE INPUT TO THE STRAIN GAUGE AMPLIFIER, UTILIZING TWO ACTIVE STRAIN GAUGES*, ONE IN COMPRESSION AND THE OTHER IN STRETCH. THIS ARRANGEMENT HAS THE EFFECT OF DOUBLING THE SENSITIVITY OF THE BRIDGE CIRCUIT. TWO EXTERNAL DUMMY RESISTORS WERE MOUNTED IN AN ENCLOSED METAL BOX. THE STRAIN GAUGES HAD THE FOLLOWING CHARACTERISTICS: (1) RESISTANCE - 120.0 $\pm$ 0.5 OHMS, (2) GAUGE FACTOR - 2.12 AND (3) 5-6 TEMPERATURE COMPENSATION. THE LAST CHARACTERISTIC MATCHES THE TEMPERATURE COMPENSATING CHARACTERISTICS OF THE METAL PLATE. THE DIMENSIONS OF THE PLATE AND THE PLACING OF THE STRAIN GAUGES WERE DERIVED FROM THE METHOD DESCRIBED IN THE MACHINERY'S HANDBOOK.**

3. STRAIN GAUGE AMPLIFIER. THE STRAIN GAUGE WAS CONNECTED TO A DC COUPLED STRAIN GAUGE AMPLIFIER.*** THIS AMPLIFIER HAD A HIGH AMPLIFICATION FACTOR EMPLOYING A TEN-TURN, THOUSAND GRADATION POTENTIOMETER AS THE GAIN CONTROL. THE EXTERNAL CIRCUIT IS BALANCED BY A BRIDGE BALANCE POTENTIOMETER AND MONITORING METER. THE OUTPUT OF THE STRAIN GAUGE AMPLIFIER WAS THEN FED TO THE MONITOR

* TYPE FAP-50-12 MANUFACTURED BY BALDWIN-LINA-HAMILTON CORPORATION, ELECTRONICS DIVISION, WALTHAM, MASSACHAUSETTS.

** MACHINERY'S HANDBOOK, THE INDUSTRIAL PRESS, 93 WORTH STREET, NEW YORK 3. PAGE 468.

*** CUSTOM MADE BY MEDELEC LTD., WOKING, SURREY, ENGLAND.

AND RECORDING OSCILLOSCOPES, AND ALSO A DIRECT RECORDING OSCILLOGRAPH, VISICORDER TYPE 1508.*

4. RECORDING ELECTRODES. SMALL SILVER PLATED SURFACE ELECTRODES, SIX MILLIMETERS IN DIAMETER, WERE PLACED OVER THE BELLY OF THE ADDUCTOR POLLICIS TO PICK UP THE MUSCLE ACTION POTENTIALS. THE GROUND ELECTRODE, A RECTANGULAR SILVER COATED PLATE, ONE BY ONE AND ONE-HALF INCHES, WAS PLACED ON THE MEDIAL SURFACE OF THE FOREARM.

5. ELECTROMYOGRAPH (E.M.G.) AMPLIFIER. THE RECORDING ELECTRODES WERE CONNECTED TO A DIFFERENTIAL INPUT ELECTROMYOGRAPH PREAMPLIFIER.** THE INPUT IMPEDANCE TO THIS AMPLIFIER IS 1.0 MEGOHM SHUNTED BY 150 MICRO FARADS. THE LOW FREQUENCY TIME CONSTANT WAS AVAILABLE FROM 0.5 TO 0.01 SECONDS. THE HIGH FREQUENCY CUT OFF WAS VARIABLE FROM 300 CYCLES PER SECOND (C.P.S.) TO 10 KC.P.S. THE PREAMPLIFIER WAS CONNECTED TO THE MONITOR AND RECORDING OSCILLOSCOPES AND ALSO TO THE DIRECT RECORDING OSCILLOGRAPH.

6. STIMULATING ELECTRODES AND FIXATION TO WRIST. THE CATHODE WAS A STUD-LIKE, SILVER PLATED ELECTRODE, ONE CENTIMETER IN DIAMETER. IT WAS HELD OVER THE ULNAR NERVE AT THE WRIST BY MEANS OF A LEATHER AND ELASTIC STRAP. IN ORDER TO USE THE LEAST POSSIBLE STIMULUS, PRESSURE WAS APPLIED TO THE CATHODE BY AN ADJUSTABLE PROBE (FIG. 2) WHICH WAS ATTACHED TO THE INNER TABLE OF THE BALL BEARING RACE. THE ANODE WAS A SILVER COATED RECTANGULAR PLATE, ONE-HALF INCH BY ONE AND ONE-HALF INCHES. IT WAS CONNECTED PERMANENTLY TO THE CAST IN SUCH A WAY THAT IT CAME INTO CONTACT WITH THE MEDIAL PORTION OF THE LOWER FOREARM PROXIMAL AND DORSAL TO THE CATHODE.

IT MAY BE NOTED THAT THE RACE, SPLINT, ELECTRODES AND PRESSURE DEVICE WERE DESIGNED SO THAT EITHER THE LEFT OR RIGHT HAND COULD BE TESTED BY SIMPLY MOVING THE RACE COMPLEX FROM ONE SIDE OF THE BED TO THE OTHER.

* MANUFACTURED BY MINNEAPOLIS HONEYWELL, HEILAND DIVISION, 5200 E. EVANS AVENUE, DENVER, COLORADO.

** MANUFACTURED BY MEDELEC LTD., WOKING, SURREY, ENGLAND.

7. NERVE STIMULATOR. A CUSTOM MADE MEDELEC* STIMULATOR WAS USED. STIMULUS AMPLITUDE WAS VARIABLE FROM 0 TO 200 VOLTS WITH AN OUTPUT IMPEDANCE OF LESS THAN 1000 OHMS. THE MONOPHASIC RECTANGULAR PULSES DELIVERED (RISE TIME 5.0 MICROSECONDS) MAY BE OF 0.1, 0.3 OR 1.0 MILLISECOND DURATION. AN ISOLATION TRANSFORMER EXISTS BETWEEN THE STIMULATING ELECTRODES AND THE NERVE STIMULATOR.

8. RECORDING APPARATUS. THE RECORDING INSTRUMENTATION CONSISTED OF THE FOLLOWING UNITS:

(I) MEDELEC* ELECTROMYOGRAPH, A FIVE INCH MONITOR OSCILLOSCOPE CONNECTED IN PARALLEL WITH AN IDENTICAL OSCILLOSCOPE CONNECTED TO A COSSOR CAMERA. EACH OSCILLOSCOPE HAD THREE CHANNELS WHICH ALLOWED FOR THE SIMULTANEOUS DISPLAY OF (A) MUSCLE ACTION POTENTIALS, (B) STRAIN GAUGE TENSION PRODUCED BY THE MUSCLE IN CONTRACTION AND, (C) A TIME MARKER WHICH ALSO PROVIDED A ZERO BASELINE FOR THE TENSION RECORD. THE 35MM COSSOR CAMERA WAS EMPLOYED FOR SINGLE OR SUPERIMPOSED SHOTS AND ALSO FOR CONTINUOUS SWEEP RECORDING ON KODAK PANATOMIC-X FILM. A THIRD SINGLE BEAM STORAGE OSCILLOSCOPE (SKIATRON)** IN PARALLEL WITH THE OTHER TWO OSCILLOSCOPES WAS EMPLOYED FOR BOTH MONITORING AND RECORDING ANY OF THE PARAMETERS RECORDED ON THE OTHER OSCILLOSCOPE BEAMS.

(II) DIRECT RECORDING OSCILLOGRAPH (VISICORDER TYPE 1508). TWO OF THE TWELVE AVAILABLE GALVANOMETERS WERE CONNECTED IN PARALLEL WITH THE SIGNAL OUTPUTS OF THE E.M.G. AND STRAIN GAUGE AMPLIFIERS. THE GALVANOMETER, USED FOR RECORDING THE TENSION HAD A FREQUENCY RESPONSE OF 300 C.P.S., WHEREAS THAT FOR RECORDING THE EVOKED MUSCLE ACTION POTENTIALS HAD A FREQUENCY RESPONSE OF 1000 C.P.S. THESE TRACES WERE RECORDED ON SPECIAL SENSITIVE PAPER WHERE THE RECORDING BECOMES VISIBLE WHEN THE PAPER IS EXPOSED TO LIGHT.

9. CALIBRATION. (I) TENSION - FOLLOWING EACH TRIAL OR CHANGE IN THE GAIN CONTROL OF THE AMPLIFIER, THE STRAIN GAUGE UNIT WAS CALIBRATED BY APPLYING A TEN POUND WEIGHT (FIG. 4) TO THE MECHANO-ELECTRIC TRANSDUCER. THE CALIBRATION WAVE

* CUSTOM MADE ELECTROMYOGRAPH BY MEDELEC LTD., WOKING, SURREY, ENGLAND.
** MANUFACTURED BY STANDARD ELEKTRIK LORENZ AKTIENGESELLSCHOFT, LORENZ WERKE STUTTGART.

WAS EITHER PHOTOGRAPHED ON THE OSCILLOSCOPE OR RECORDED ON THE VISICORDER.

(11) ACTION POTENTIAL - WHEN IT BECAME NECESSARY TO DETERMINE THE AMPLITUDE IN MILLIVOLTS (MV) OF THE EVOKED MUSCLE ACTION POTENTIAL, AN INTERNAL CALIBRATOR BUILT INTO THE E.M.G. PREAMPLIFIER SUPPLIED A SQUARE WAVE PULSE OF KNOWN AMPLITUDE WHICH WAS ALSO EITHER PHOTOGRAPHED ON THE OSCILLOSCOPE OR RECORDED ON THE VISICORDER.

C. SUBJECTS

1. SELECTION. TEN MALES AND EIGHT FEMALES VOLUNTEERED TO TAKE PART IN THE STUDY. THE SUBJECTS RANGED IN AGE FROM 22 - 45 YEARS WITH AN AVERAGE OF 28 YEARS. THE SUBJECTS WERE EMPLOYED IN THE REHABILITATION DEPARTMENT AT THE UNIVERSITY HOSPITAL IN EDMONTON, ALBERTA.

2. GROUPING. AS A MATTER OF CONVENIENCE, INDIVIDUAL SUBJECTS WERE ASKED TO BELONG TO ONE OF THREE GROUPS:

GROUP "A" (ARTIFICIAL EXERCISE - N = 9) - THESE SUBJECTS VOLUNTEERED TO HAVE THE ULNAR INNERVATED MUSCLES OF THEIR NON-DOMINANT HANDS UNDERGO A SIX SECOND, DAILY, TETANIC CONTRACTION.

GROUP "V" (VOLUNTARY EXERCISE - N = 5) - THESE SUBJECTS VOLUNTEERED TO TRY TO DO A SIX SECOND, DAILY, MAXIMAL, VOLUNTARY, ISOMETRIC CONTRACTION OF THE ULNAR INNERVATED MUSCLES OF THEIR NON-DOMINANT HANDS.

GROUP "C" (CONTROL - N = 4) - THESE SUBJECTS MADE UP THE CONTROL GROUP. THEY CARRIED ON THEIR NORMAL EVERYDAY ACTIVITY. IT SHOULD BE NOTED THAT THE DOMINANT HANDS OF ALL OF THE SUBJECTS WERE TESTED IN EXACTLY THE SAME WAY AS THE EXERCISED NON-DOMINANT HAND. THESE MEASURES ON THE DOMINANT HAND, WHICH UNDERWENT NO EXERCISE PROGRAM, ALSO ACTED AS A CONTROL GROUP.

D. LOCATION AND DURATION OF EXPERIMENT

THIS EXPERIMENT WAS CONDUCTED IN THE ELECTROMYOGRAPHY LABORATORY OF THE UNIVERSITY HOSPITAL, EDMONTON, FROM FEBRUARY 20, 1964 TO APRIL 9, 1965. THE EXPERIMENTAL PERIOD WAS OF FIVE WEEKS' DURATION.

E. TEST PROCEDURE

1. Tests. EACH SUBJECT UNDERWENT THREE STRENGTH TESTS - GRIP TENSION, TETANUS TENSION AND MERTON'S TENSION, AND DATA WAS DERIVED FROM THE TETANUS TENSION TO DETERMINE THE FATIGUE-TENSION RATIO.

(I) GRIP TENSION - THIS IS THE MAXIMUM TENSION THE SUBJECT CAN PRODUCE VOLUNTARILY IN THE THUMB REGARDLESS OF ITS ANGLE OF PULL OR ITS ANATOMICAL POSITION.

(II) TETANUS TENSION - THIS IS THE TENSION PRODUCED BY THE THUMB WHEN THE SUBJECT HAD A SUPRAMAXIMAL STIMULATION OF THE ULNAR NERVE AT A FREQUENCY OF 50 C.P.S. FOR SIX SECONDS.

(III) MERTON'S TENSION - THIS IS THE TENSION PRODUCED BY THE THUMB WHEN THE SUBJECT EXERTS HIS MAXIMUM FORCE ALONG THE LINE OF PULL THAT THE THUMB TOOK DURING THE TETANIC CONTRACTION, WHILE KEEPING THE METACARPO-PHALANGEAL AND INTER-PHALANGEAL JOINTS OF THE THUMB EXTENDED.

(IV) FATIGUE-TENSION RATIO IS THE TETANUS TENSION AFTER TWO MINUTES OF CONTINUOUS STIMULATION AT A FREQUENCY OF 25 CYCLES PER SECOND DIVIDED BY THE MAXIMUM TETANUS TENSION ON INITIAL STIMULATION AT THE SAME FREQUENCY.

2. Testing Procedure. THE PURPOSE OF THE EXPERIMENT, THE MECHANICAL APPARATUS, AND THE PROCEDURE TO BE FOLLOWED WERE CAREFULLY EXPLAINED TO EACH SUBJECT BEFORE THE EXPERIMENT BEGAN. THE SUBJECTS WERE NOT ALLOWED TO TRAIN WITH THE APPARATUS BEFORE THEIR INITIAL TEST TRIAL.

RELIABILITIES FOR GRIP TENSION, TETANUS TENSION, MERTON'S TENSION, AND FATIGUE-TENSION RATIO WERE ESTABLISHED BY TESTING THE SUBJECTS IN GROUPS A AND V ON SEPARATE DAYS. THE SECOND TEST WAS USED AS THE PRE-TEST STANDARD FOR THESE SUBJECTS. THEY WERE TESTED FOR THE ABOVE MENTIONED PARAMETERS A THIRD TIME AT THE CONCLUSION OF THE EXPERIMENTAL PERIOD.

THE DOMINANT HANDS OF ALL THE SUBJECTS AND THE NON-DOMINANT HANDS OF THE SUBJECTS IN GROUP C WERE TWICE TESTED FOR THE PARAMETERS UNDER DISCUSSION, ONCE AT THE BEGINNING AND ONCE AT THE END OF THE EXPERIMENT.

THE TESTS WERE ADMINISTERED AS FOLLOWS:

(I) THE SUBJECT ASSUMED A SUPINE POSITION ON THE BED. THE SKIN AREA UPON WHICH THE RECORDING ELECTRODES WERE PLACED WAS FIRST CLEANED WITH ALCOHOL. THE RECORDING AND INDIFFERENT ELECTRODES WERE THEN PLACED ON THEIR RESPECTIVE HAND POSITIONS.

(II) POSITIONING OF RECORDING ELECTRODE (FIG. 5) - A LINE IS DRAWN FROM THE MID-POINT OF THE DISTAL FLEXOR WRIST CREASE TO THE MID-POINT OF THE FLEXOR CREASE OF THE THIRD METACARPO-PHALANGEAL JOINT. THE MID-POINT OF THIS LINE IS MARKED WITH A CROSS. 'A'

A SECOND LINE IS DRAWN FROM THE MID-POINT OF THE DISTAL FLEXOR WRIST CREASE TO THE MID-POINT OF THE FLEXOR CREASE OF THE FIRST METACARPO-PHALANGEAL JOINT (No. 2 IN FIG. 5). ONE THIRD OF THE DISTANCE MEASURED FROM POINT 'A' TO No. 2 IS MARKED (E FIG. 5) AND THIS IS THE POSITION FOR THE RECORDING ELECTRODE. THE INDIFFERENT ELECTRODE IS PLACED ON THE FLEXOR SURFACE OF THE BASE OF THE FIRST PHALANX OF THE THUMB.

(III) THE STIMULATING ELECTRODE WAS LOOSELY STRAPPED TO THE WRIST IN CLOSE PROXIMITY TO THE ULNAR NERVE AT THE WRIST.

(IV) THE SUBJECT THEN PLACED HIS ARM IN THE CAST MOULD. THE STRAP AND CLAMPS THAT WERE USED TO STABILIZE THE HAND WERE LOOSELY FASTENED ACROSS THE FOREARM, WRIST AND HAND. ONCE THE COMFORT OF THE SUBJECT WAS ASSURED THE STRAPS HOLDING THE FOREARM AND HAND IN THE SPLINT WERE TIGHTENED.

(V) THE GRIP TENSION OF THE SUBJECT WAS RECORDED FOR SIX SECONDS.

(VI) THE STRAPS WERE LOOSENED AND THE SUBJECT WAS ALLOWED TO REST FOR TWO MINUTES. EMPLOYING THE PRESSURE DEVICE, THE MINIMAL STIMULUS THAT WAS NEEDED TO PRODUCE A MAXIMUM EVOKED POTENTIAL FROM THE MUSCLE WAS DETERMINED. THE STRAPS WERE AGAIN TIGHTENED SO THAT THE FOREARM AND HAND WERE HELD FIRMLY IN THE CAST. THE VOLTAGE WAS THEN INCREASED 10 TO 20 PERCENT AND THE FREQUENCY OF THE NERVE

STIMULATOR WAS CHANGED FROM ONE C.P.S. TO 50 C.P.S.

(VII) THE TETANIC TENSION OF THE SUBJECT WAS RECORDED FOR SIX SECONDS. AT APPROXIMATELY THE THREE SECOND MARK THE VOLTAGE WAS INCREASED AN ADDITIONAL 10 TO 20 PERCENT TO CHECK THAT THE STIMULUS WAS SUPRAMAXIMAL. THE ANGLE TO WHICH THE OUTER RACE TURNED WAS RECORDED.

(VIII) THE STRAPS WERE LOOSENED, THE PRESSURE DEVICE WAS RELEASED AND THE SUBJECT WAS ALLOWED TO REST FOR TWO MINUTES. THE FOREARM AND HAND WERE AGAIN STRAPPED FIRMLY IN THE RACE.

(IX) MERTON'S TENSION WAS RECORDED FOR SIX SECONDS. BEFORE AND DURING THE RECORDING OF THE GRIP TENSION AND MERTON'S TENSION, THE SUBJECT WAS URGED TO DO HIS VERY BEST.

(X) THE STRAPS WERE AGAIN LOOSENED AND THE SUBJECT WAS ALLOWED TO REST FOR TWO MINUTES. UTILIZING THE PRESSURE DEVICE, THE MINIMAL STIMULUS THAT WAS NEEDED TO PRODUCE A MAXIMUM EVOKED POTENTIAL WAS AGAIN DETERMINED. THE FOREARM AND HAND WERE FIXED TIGHTLY IN THE RACE. THE VOLTAGE WAS INCREASED TEN TO TWENTY PERCENT AND THE FREQUENCY OF THE NERVE STIMULATOR WAS CHANGED FROM ONE C.P.S. TO 25 C.P.S.

(XI) THIS STIMULUS WAS THEN APPLIED TO THE ULNAR NERVE AT THE WRIST CONTINUOUSLY FOR A PERIOD OF TWO MINUTES. THE VOLTAGE WAS INCREASED AN ADDITIONAL 10 TO 20 PERCENT FOR ONE TO TWO SECONDS AT THE FIVE SECOND AND THE 15 SECOND MARK TO INSURE THAT THE STIMULUS WAS SUPRAMAXIMAL. AFTER TWO MINUTES IT WAS DISCONTINUED AND TURNED ON FOR FIVE SECOND INTERVALS AT THE 2, 10, 25, 60, 90, 120 SECOND MARKS DURING THE RECOVERY. THE TENSION AS WELL AS THE E.M.G. WERE RECORDED FOR THE FATIGUE CURVE AND ITS RECOVERY.

(XII) AFTER HE HAD TAKEN HIS ARM OUT OF THE RACE COMPLEX, IT WAS STRESSED TO THE SUBJECT THAT HE WAS UNDER NO OBLIGATION TO CONTINUE WITH THE EXPERIMENT, AND THAT HE DID NOT HAVE TO REPORT TO THE LABORATORY THE NEXT DAY IF HE DID NOT WANT TO.

3. EXPERIMENTAL PROCEDURE.

(I) ARTIFICIAL EXERCISE - AT APPROXIMATELY THE SAME TIME OF DAY, THE SUBJECTS EXERCISED FIVE DAYS A WEEK FOR A PERIOD OF FIVE WEEKS. THE EXPERIMENTAL PROCEDURE WHICH WAS FOLLOWED FOR GROUP A IS AS FOLLOWS:

(A) THE SUBJECTS ASSUMED A SUPINE POSITION ON THE BED. WHEN POSITION 'E' WAS LOCATED, THE SURFACE OF THE SKIN WAS SCRATCHED SO THAT IT WOULD NOT BE NECESSARY TO MAKE THE MEASUREMENTS EACH DAY. THE SKIN WAS CLEANED WITH ALCOHOL AND THE RECORDING ELECTRODES WERE PLACED IN POSITION. THE STIMULATING ELECTRODE WAS LOOSELY STRAPPED TO THE WRIST IN CLOSE PROXIMITY TO THE ULNAR NERVE AT THE WRIST.

(B) THE SUBJECT PLACED HIS ARM IN THE CAST MOULD. THE STRAPS WERE LOOSELY FASTENED ABOUT THE FOREARM, WRIST AND HAND. ONCE AGAIN THE PRESSURE DEVICE WAS USED IN DETERMINING THE MINIMAL VOLTAGE NECESSARY TO ELICIT THE MAXIMUM EVOKED POTENTIAL. THE VOLTAGE WAS THEN INCREASED 10 TO 20 PERCENT AND THE FREQUENCY OF THE NERVE STIMULATOR WAS CHANGED FROM ONE C.P.S. TO 50 C.P.S. THE HAND WAS FIXED INTO PLACE WITH THE CLAMPS.

(C) THE TETANIC TENSION OF THE SUBJECT WAS RECORDED FOR A PERIOD OF SIX SECONDS. AT APPROXIMATELY THE THREE SECOND MARK THE VOLTAGE WAS INCREASED AN ADDITIONAL 10 TO 20 PERCENT TO CHECK THAT THE STIMULUS WAS SUPRAMAXIMAL. THE ANGLE TO WHICH THE OUTER RACE TURNED WAS RECORDED.

(D) THE SUBJECT WAS THEN RELEASED FROM THE RACE COMPLEX.

(II) VOLUNTARY EXERCISE - THE EXPERIMENTAL PROCEDURE WHICH WAS FOLLOWED FOR GROUP V IS AS FOLLOWS:

(A) THE SUBJECT ASSUMED A SUPINE POSITION ON THE BED AND IMMEDIATELY PLACED HIS HAND IN THE CAST MOULD. THE STRAP AND CLAMPS WERE FITTED TIGHTLY ABOUT THE FOREARM AND HAND.

(B) MERTON'S TENSION WAS RECORDED FOR A PERIOD OF SIX SECONDS.

(C) THE SUBJECT WAS THEN RELEASED FROM THE RACE COMPLEX.

III

RESULTS

A. Reliability Coefficients

B. Tests of Significance

CHAPTER III

RESULTS

A. RELIABILITY COEFFICIENTS*

THE RELIABILITY COEFFICIENTS OF THE FOUR PARAMETERS MEASURED WERE CALCULATED ON A TEST-RETEST BASIS. THEY ARE AS FOLLOWS:

1. GRIP TENSION (N = 13) - .694
2. TETANIC TENSION (N = 14) - .884
3. MERTON'S TENSION (N = 14) - .704
4. FATIGUE - TENSION RATIO (N = 13) - .96

B. TESTS OF SIGNIFICANCE**

THE TESTS OF SIGNIFICANCE USED TO DETERMINE THE T-RATIOS OF THE ABOVE PARAMETERS FOR GROUPS A, V, AND C IS OUTLINED BY FERGUSON.

1. ARTIFICIAL EXERCISE - GROUP A (N = 9). AFTER 5 WEEKS OF DAILY TETANIC CONTRACTIONS, 9 SUBJECTS SHOWED (TABLE IV) AN INCREASE IN GRIP TENSION FROM AN INITIAL MEAN OF 28.4 POUNDS TO A FINAL MEAN OF 31.34 POUNDS.

THIS REPRESENTS A MEAN INCREASE OF 2.94 POUNDS WITH A STANDARD DEVIATION (S.D.) OF 1.99. THESE RESULTS ARE SIGNIFICANT AT THE 0.01 LEVEL OF SIGNIFICANCE.

THESE SAME SUBJECTS DEMONSTRATED (TABLE V) AN INCREASE IN TETANIC TENSION FROM AN INITIAL MEAN OF 14.32 POUNDS TO A FINAL TENSION OF 16.03 POUNDS. THIS REPRESENTS AN INCREASE OF 1.71 POUNDS (S.D. = 1.1) WHICH IS SIGNIFICANT AT THE 0.01 LEVEL OF CONFIDENCE.

GROUP A DID NOT SHOW SIGNIFICANT*** CHANGES IN EITHER MERTON'S TENSION OR THE FATIGUE-TENSION RATIO, WHICH HAD MEAN DIFFERENCES OF 0.5 (S.D. = 0.056) AND 0.18 (S.D. = 0.023) RESPECTIVELY.

2. VOLUNTARY EXERCISE - GROUP V (N = 5). THE SUBJECTS WHO EXERCISED BY DOING A DAILY, SIX SECOND, MAXIMUM, VOLUNTARY, ISOMETRIC CONTRACTION DID NOT SHOW

* TABLES I AND II.
** TABLE III.
*** THE 0.05 LEVEL OF CONFIDENCE WAS THE MINIMUM LEVEL ACCEPTED FOR SIGNIFICANCE.

STATISTICALLY SIGNIFICANT CHANGES IN ANY OF THE FOUR PARAMETERS MENTIONED ABOVE. THE MEAN DIFFERENCES WITH THEIR STANDARD DEVIATIONS ARE AS FOLLOWS:

GRIP TENSION	3.91 (S.D. = 4.3)
TETANIC TENSION	2.24 (S.D. = 3.6)
MERTON'S TENSION	1.58 (S.D. = 4.6)
FATIGUE-TENSION RATIO	0.017 (S.D. = 1.1)

3. CONTROL GROUP C (N = 4). THIS CONTROL GROUP ALSO DID NOT DEMONSTRATE STATISTICALLY SIGNIFICANT CHANGES IN ANY OF THE FOUR PARAMETERS UNDER DISCUSSION. THE MEAN DIFFERENCES FOR THE EXERCISED HAND IN GROUP C SUBJECTS WERE:

GRIP TENSION	2.35 (S.D. = 1.7)
TETANIC TENSION	1.17 (S.D. = 1.8)
MERTON'S TENSION	0.15 (S.D. = 1.5)
FATIGUE-TENSION RATIO	0.23 (S.D. = 0.08)

FOR GROUPS A AND V THE CONTROL MEASURES TAKEN ON THE DOMINANT HAND ALSO DID NOT SHOW ANY SIGNIFICANT CHANGES IN GRIP TENSION, TETANIC TENSION, MERTON'S TENSION, OR THE FATIGUE-TENSION RATIO. THE MEAN DIFFERENCES FOR THE DOMINANT HAND IN GROUPS A, V, AND C WERE AS FOLLOWS:

	GROUP A	GROUP V	GROUP C
GRIP TENSION	1.84 (S.D. = 4.59)	2.38 (S.D. = 3.1)	3.1 (S.D. = 4.0)
TETANIC TENSION	0.83 (S.D. = 1.5)	0.56 (S.D. = 1.9)	1.03 (S.D. = 2.1)
MERTON'S TENSION	0.133 (S.D.= 1.6)	1.8 (S.D. = 3.0)	1.30 (S.D. = 1.3)
FATIGUE-TENSION RATIO	0.01 (S.D. = 1.07)	-0.074 (S.D.=0.075)	-0.02(S.D. =0.01)

IV

DISCUSSION

A. Information Gained from Pilot Studies

B. Control of Variables

C. Reliability

D. Limitations of the Study

E. Effects of Artificial Exercise

F. Effects of Voluntary Exercise

CHAPTER IV

DISCUSSION

A. INFORMATION GAINED FROM PILOT STUDIES

In using Merton's apparatus, problems were encountered which necessitated a number of pilot projects which provided information on a number of noteworthy points.

1. Mechanical Apparatus. The mechanical device which was used in this experiment was modelled after that described by Merton. Although the problems investigated by Merton were not directly related to the problems in this study, his ingenious contrivance was almost ideal for a well controlled investigation of the effects of artificial stimulation on muscle strength and fatigue.

Merton's rationale for selecting the adductor pollicis and this particular technique for a study of muscle strength and fatigue follows, interspersed with comments about the manner in which it was utilised in this study.

> "The great advantage of the adductor pollicis muscle is that under appropriate conditions it is the only ulnar supplied muscle acting on the thumb and also the only muscle used in voluntary adduction. Thus voluntary force and tension developed with electrical stimulation can be compared in reasonable certainty that the same muscle mass is producing both. The muscles that may interfere in the comparison by contributing to the voluntary tension are the median supplied muscles of the thenar eminence (particularly the opponens pollicis), the flexor pollicis longus, and that part of the first dorsal interosseus muscle that arises from the first metacarpal....." (21:554).

Rowntree reports that the classical case where the ulnar nerve innervates the abductor digiti quinti, the interossei, and the adductor pollicis muscles occurred in only 33 percent of the 124 cases he studied. For the purposes of this experiment it is of little consequence if this is the case in our subjects or not for as long as the subject pulled along the angle the thumb takes during a tetanic contraction the muscles innervated by the ulnar nerve will probably contribute the greater portion of the tension produced by a voluntary contraction.

As this study is not primarily concerned with the comparison of the voluntary force and the tension developed with electrical stimulation, the problem of

WHETHER OR NOT THE ADDUCTOR POLLICIS MUSCLE IS THE ONLY MUSCLE USED IN VOLUNTARY ADDUCTION WILL NOT BE DISCUSSED.

MERTON GOES ON TO DETAIL THE METHOD BY WHICH THE INFLUENCE OF THE OPPONENS POLLICIS IS ELIMINATED:

> "....THE AXIS OF ROTATION OF THE BALLBEARING RACE WAS APPROXIMATELY COINCIDENT WITH THE THIRD METACARPAL, THE BONE FROM WHICH THE ADDUCTOR POLLICIS ARISES. WHEN THIS MUSCLE CONTRACTED THERE SHOULD BE LITTLE TENDENCY FOR THE RACE TO TURN. THE OPPONENS MUSCLE, HOWEVER, PASSES TO THE PALMAR SIDE OF THE AXIS, AND WHEN IT CONTRACTS THE RACE SHOULD TURN IN DIRECTION OF THUMB OPPOSITION. IN PRACTICE, THE LINE OF THE AXIS WAS SO ADJUSTED THAT WHEN THE ULNAR NERVE WAS TETANIZED ALONE THE RACE TOOK UP A POSITION WITH THE THUMB A LITTLE FORWARD OF THE PLANE OF THE PALM, BUT WHEN THE MEDIAN NERVE WAS SIMULTANEOUSLY EXCITED A LARGE MOVEMENT OF OPPOSITION TOOK PLACE. WITH BRIEF VOLUNTARY EFFORTS IT IS FOUND THAT THE TENSION THAT CAN BE EXERTED IS NOT OBVIOUSLY INCREASED BY THE USE OF THE OPPONENS IF THE RACE IS FREE TO TURN. PRESUMABLY BOTH MUSCLES ARE THEN WORKING AT A LESSER MECHANICAL ADVANTAGE. IF THE RACE IS CLAMPED, USE OF THE OPPONENS GIVE ABOUT A 30% INCREASE IN TENSION..." (21:554).

WITH THE APPARATUS USED IN THIS STUDY, THE SUBJECT COULD VERY SIGNIFICANTLY INCREASE THE TENSION BY BRINGING THE OPPONENS POLLICIS INTO USE. HENCE HE WAS NOT ALLOWED TO SWING THE RACE OFF THE ANGLE, ESTABLISHED FROM THE TETANIC CONTRACTION, WHILE HE WAS RECORDING MERTON'S TENSION. MERTON CONTINUES:

> "THE ACTION OF THE FLEXOR POLLICIS LONGUS WAS RENDERED INAPPRECIABLE FIRSTLY BY ENCOURAGING THE SUBJECT NOT TO FLEX THE PHALANGES OF THE THUMB, AND SECONDLY BY AN AUTOMATIC COMPENSATION IN THE TENSION RECORDER. THE LATTER CONSISTS OF AN INVERTED STEEL U-MEMBER DISPOSED SO THAT THE PULL OF THE THUMB DIVERGES THE LIMBS, THE TRANSDUCER MEASURING THE DIVERGENCE. FOR A GIVEN FORCE THE LARGEST READING IS OBTAINED WHEN THE DIRECTION OF PULL IS NOT PARALLED TO THE LINE JOINING THE ENDS OF THE LIMBS BUT MAKE AN ANGLE OF ABOUT 30^{o} ABOVE THE HORIZONTAL. WHEN THE PROXIMAL PHALANX IS FLEXED, HOWEVER, THE LINE OF PULL BECOMES MORE NEARLY HORIZONTAL SO THAT THE SAME TENSION PRODUCES A SMALLER DEFLECTION ON THE RECORD. THE DIMENSIONS OF THE SYSTEM ARE SUCH THAT THE MAXIMUM TENSION A SUBJECT CAN RECORD IS LITTLE AFFECTED BY THE FLEXION OF THE PHALANGES, THE INCREASE DUE TO USE OF THE LONG FLEXOR BEING OFFSET BY THE LESS EFFECTIVE DIRECTION OF PULL....." (21:555).

THE CHARACTERISTICS OF THE TRANSDUCER EMPLOYED IN THIS EXPERIMENT WERE SUCH THAT FOR A GIVEN FORCE THE LARGEST READING WAS OBTAINED WHEN THE DIRECTION OF THE PULL WAS PERPENDICULAR TO THE SINGLE STEEL MEMBER (FIG. 2). AS THE PROXIMAL PHALANX IS FLEXED, THE LINE BECOMES MORE NEARLY HORIZONTAL RESULTING IN THE SAME FORCE PRODUCING A SMALLER DEFLECTION ON THE MONITOR OSCILLOSCOPE OR

VISICORDER. HOWEVER WITH THIS DEVICE, IF THE SUBJECT FLEXES HIS THUMB, THE ADDED TENSION PRODUCED BY THE FLEXOR POLLICIS LONGUS IS SIGNIFICANTLY LARGER THAN THE LOSS OF TENSION RESULTING FROM THE LESS EFFECTIVE ANGLE OF PULL ON THE TRANSDUCER. CONSEQUENTLY ALL OF THE SUBJECTS WERE INSTRUCTED NOT TO FLEX THEIR THUMBS WHEN THEY WERE DOING THE EXERCISE DESCRIBED UNDER THE SUB-HEADING MERTON'S-TENSION IN CHAPTER II.

MERTON CONTINUES:

> "ANY CONTRIBUTION OF THE FIRST DORSAL INTEROSSEUS MUSCLE WAS MINIMIZED BY CUTTING AWAY THE SPLINT SO THAT THERE IS NOTHING AGAINST WHICH TO BRACE THE INDEX FINGER, INTO WHICH IT IS INSERTED. IF, DESPITE THIS PRECAUTION, A SMALL COMPONENT OF TENSION FROM THE INTEROSSEUS STILL REMAINS IT IS OF LITTLE IMPORTANCE, FOR THIS MUSCLE IS ALSO SUPPLIED BY THE ULNAR NERVE... ....." (21:555).

FOR THE PURPOSES OF THIS STUDY THE ELIMINATION OF THE INFLUENCE OF THE FIRST DORSAL INTEROSSEUS IS NOT SIGNIFICANT AS IT IS ONLY RARELY NOT SUPPLIED BY THE ULNAR NERVE WHICH MEANS THAT DURING ELECTRICAL STIMULATION IT IS BEING TETANIZED AND THUS CONTRIBUTING TO THE ESTABLISHMENT OF THE ANGLE OF PULL OF THE THUMB. WHEN THE SUBJECT VOLUNTARILY PULLS ALONG THIS ANGLE, PRESUMABLY, THE FIRST DORSAL INTEROSSEUS IS CONTRACTING AND CONTRIBUTING TO THE TOTAL FORCE WHICH IS DEVELOPED.

2. <u>MERTON'S TENSION.</u> DURING THE TEST TRIALS FOR MERTON'S TENSION NO TIME LIMIT WAS PLACED ON THE SUBJECT, HE WAS SIMPLY ASKED TO PRODUCE THE MAXIMUM AMOUNT OF TENSION HE POSSIBLY COULD ALONG THE LINE OF PULL ADOPTED BY THE TETANIC TENSION. USUALLY THIS MAXIMUM WAS REACHED WITHIN SIX SECONDS. FOR THE EXERCISE PROGRAM THE SUBJECT WAS ASKED TO PRODUCE HIS MAXIMUM TENSION AND HOLD IT FOR SIX SECONDS. USUALLY THE ENTIRE CONTRACTION LASTED LESS THAN 10 SECONDS.

IT WOULD ENHANCE THE DESIGN OF THIS EXPERIMENT IF BOTH EXPERIMENTAL GROUPS DID AS NEAR AS POSSIBLE THE SAME AMOUNT OF EXERCISE. THE WORKING HYPOTHESIS FOR THE COMPARISON OF MERTON'S TENSION AND THE TETANIC TENSION IS THAT THEORETICALLY VIRTUALLY ALL OF MERTON'S TENSION IS DEVELOPED BY THE SAME MUSCLES THAT ARE RESPONSIBLE FOR THE TENSION IN A TETANIC CONTRACTION, NAMELY THE ULNAR SUPPLIED MUSCLES OF THE THUMB AND THAT IT IS POSSIBLE FOR THE VOLUNTARY FORCE PRODUCED BY

THESE MUSCLES TO EQUAL THE TETANIC TENSION OF THESE SAME MUSCLES (21).

3. Grip Tension. GRIP TENSION WAS INTRODUCED INTO THE DESIGN OF THE EXPERIMENT DURING PILOT STUDIES BECAUSE IT WAS THOUGHT THAT, SINCE IT IS VERY SIMILAR TO A NORMAL GRIP, THAT THIS VOLUNTARY EXERCISE COULD BE DONE WITH A HIGHER DEGREE OF RELIABILITY THAN THE EXERCISE ASSOCIATED WITH MERTON'S TENSION WHICH IS AN UNNATURAL MOVEMENT AND DIFFICULT TO PERFORM WITHOUT A NUMBER OF TRAINING TRIALS.

4. Stimulation. THE MOST RELIABLE AND EFFECTIVE STIMULUS WAS GIVEN TO THE SUBJECT WHEN THE STIMULATING ELECTRODES DESCRIBED UNDER METHODS WERE USED AND WHEN THE ANODE WAS PLACED DORSAL AND PROXIMAL TO THE CATHODE.

WITH THE CATHODE JUST STRAPPED TO THE WRIST, IT WAS EXCEEDINGLY DIFFICULT TO MAINTAIN A MAXIMAL STIMULUS BECAUSE UPON STIMULATION FLEXOR CARPI ULNARIS CONTRACTS CAUSING ITS TENDON TO BECOME TAUT LIFTING OR MOVING THE CATHODE OFF THE ULNAR NERVE. TO ENSURE THAT A MAXIMAL STIMULATION WAS MAINTAINED A PRESSURE ARM WAS USED. THIS DEVICE ALLOWED FOR THE ULNAR NERVE TO BE MORE EFFECTIVELY COMPRESSED RESULTING IN A DROP IN THE VOLTAGE REQUIRED FOR A MAXIMAL STIMULATION.

IN AN ADDITIONAL EFFORT TO ENSURE SUPRAMAXIMAL STIMULATION, THE STIMULATING VOLTAGE WAS INCREASED UP TO 40% OVER THE THRESHOLD MAXIMUM VOLTAGE, FOR A FEW SECONDS AT A TIME TO SEE IF THERE WAS ANY INCREASE IN AMPLITUDE AFTER EVOKED POTENTIAL INDICATING THAT THE STIMULUS WAS SUBMAXIMAL.

5. Muscle Tension Related To Muscle Length. IT IS WELL KNOWN THAT THE AMOUNT OF TENSION THAT CAN BE PRODUCED BY A MUSCLE INCREASES AS THE LENGTH OF THE MUSCLE INCREASES UP TO A OPTIMUM LENGTH AFTER WHICH THE TENSION DECREASES. THIS FACT CAN BE READILY VERIFIED BY USING MERTON'S APPARATUS AND ELECTRICAL STIMULATION. TO MINIMIZE THIS VARIABLE A PLASTER MOULD WAS MADE FOR THE HAND, THREE STRAPS WERE PLACED ACROSS THE SUBJECT'S ARM AND HAND, AND AFTER EVERY TRIAL THE HOLE NUMBER* INDICATING THE LENGTH OF THE MUSCLE WAS NOTED. THIS NUMBER VARIED LITTLE FROM DAY TO DAY FOR EACH INDIVIDUAL SUBJECT.

* THE STEEL PLATE CONNECTING THE WIRE FROM THE THUMB TO THE TRANSDUCER WAS PAINTED DIFFERENT COLORS EVERY FOUR HOLES.

THE FARTHER BACK THE THUMB WAS PULLED THE HIGHER THE LEVEL OF THE RESTING TENSION. THEREFORE AS AN ADDED PRECAUTION ALL OF THE MEASUREMENTS WERE TAKEN FROM THE RESTING LEVEL.

6. POSITION OF ARM AND HAND. THE AMOUNT OF TENSION PRODUCED IN EITHER A VOLUNTARY EFFORT OF TETANIC CONTRACTION COULD BE GREATLY INFLUENCED BY THE POSITION OF THE ARM AND HAND IN THE SPLINT. TO ELIMINATE MOVEMENT AS FAR AS POSSIBLE A STRAP WAS PLACED ACROSS THE FOREARM TO PREVENT THE SUBJECT FROM PULLING HIS ARM OUT OF THE SPLINT AND A CLAMP WAS TIGHTENED ACROSS THE PROXIMAL PORTION OF THE CARPAL BONES SO THAT THE SUBJECT COULD NOT ROTATE OR EXTEND HIS WRIST. TO ELIMINATE THE FORCE CONTRIBUTED BY FLEXING THE FINGERS A CLAMP WAS PUT ACROSS THE PALM OF THE HAND BELOW THE HEADS OF THE METACARPALS, AND THE DISTAL FLEXOR CREASE OF THE PALM. THE EFFECTIVENESS OF THIS ARRANGEMENT IS ATTESTED TO BY THE FACT THAT THE ANGLE OF PULL THE THUMB TOOK DURING A TETANIC CONTRACTION WAS EXTREMELY CONSISTENT FOR EACH INDIVIDUAL SUBJECT AND ALSO THAT SUCCESSIVE MEASURES, WITH THE SUBJECT BEING RELEASED FROM RACE AND THEN PLACING HIS HAND IN AGAIN, OF GRIP TENSION AND TETANIC TENSION WERE ALMOST IDENTICAL.

B. CONTROL OF VARIABLES

A NUMBER OF VARIABLES WHICH HAVE BEEN FOUND TO INFLUENCE THE STRENGTH OR FATIGUE SCORES OF INDIVIDUALS AND HOW THEY WERE CONTROLLED IN THIS STUDY ARE AS FOLLOWS:

1. TIME OF DAY. SOME INVESTIGATORS HAVE FOUND THAT THE STRENGTH OF INDIVIDUALS WAS GREATER IN THE AFTERNOON THAN IN THE MORNING (DARCUS, BECHTAL, WRIGHT).*

HISLOP SUGGESTS THAT:

> "THE MAGNITUDE OF DIFFERENCE BETWEEN MORNING AND AFTERNOON STRENGTH IS PROBABLY NOT SUFFICIENT TO MAKE ITSELF MANIFEST IN A MANUAL MUSCLE TEST, NEVERTHELESS, CONSIDERATION SHOULD BE GIVEN TO UNIFORM TIMES OF TESTING IN THE CLINIC." (11:37)

THEREFORE IN AN EFFORT TO CONTROL THE VARIABLES AS MUCH AS POSSIBLE THE SUBJECTS WERE TESTED AND EXERCISED AT APPROXIMATELY THE SAME TIME OF DAY.

* CITED IN HISLOP, H. J., "QUANTITATIVE CHANGES IN HUMAN MUSCULAR STRENGTH DURING ISOMETRIC EXERCISE." J.A. P.T.A., VOL. 43, NO. 1, PP. 21-38.

2. Social Facilitation. A number of authors have established that voluntary performance may be altered by the social structure of the testing situation (7, 16, 22). Consequently only three people were present in the laboratory while the subjects were being tested. They were Mr. Ed. Kleebaum, lab. technician, Dr. M.T.F. Carpendale, Director of the Rehabilitation Department at the University of Alberta and the writer.

3. Motivation Of The Subject. The testing and experimental procedure was the same for each subject. He was verbally familiarized with the testing procedure and the apparatus. In order not to enhance the second limitation the subjects were not allowed any pre-experimental trials on the apparatus.

In preliminary studies it was decided that a meter registering the tension exerted enabled the subject to better his performance. This gauge was placed in front of the subject while the grip tension was being recorded. It was not used while Merton's tension was being recorded because the subject's attention would become divided and he would not maintain the angle of pull.

4. Frequency For Tetanization. The evidence that the tetanizing frequency of 50 maximal shocks per second is sufficient to provide for a complete tetanus is as follows:

(I) Bigland and Lippold found that the frequency of discharge of motor units in the adductor pollicis and abductor digiti quinti never exceeded 50 per second.

(II) Lindsley determined the frequency range of individual motor units in voluntary muscle contractions. He investigated several muscles and the highest frequency observed was 50 per second. The discussion of this article includes additional references with regard to the number of stimuli necessary to produce a complete tetanus.

(III) Merton showed that the amount of tension developed by the muscle increased as the frequency increased up to 50 maximal shocks per second, after which a rise in frequency did not increase the tetanic tension.

However it has been found on two subjects in this study that a maximal

STIMULUS GIVEN AT A RATE OF 100 C.P.S. WOULD RESULT IN A 10% INCREASE IN THE TENSION PRODUCED BY A FREQUENCY OF 50 C.P.S. PRESUMABLY THE FREQUENCY AT WHICH A COMPLETELY FUSED TETANUS WILL OCCUR MAY VARY FROM SUBJECT TO SUBJECT.

IT WAS ASSUMED THAT A FREQUENCY OF 50 C.P.S. WOULD ACTIVATE AT LEAST 90% OF THE MUSCLE'S POTENTIAL STRENGTH. AS LONG AS THE LEVEL OF ACTIVATION IS CONSISTENT THE DEGREE OF ACTIVATION OVER 90% IS OF MINOR IMPORTANCE.

5. FREQUENCY FOR FATIGUE-TENSION RATIO. THE OBJECTIVE OF THIS TEST WAS TO FATIGUE THE MUSCLE AS MUCH AS POSSIBLE WITHOUT PRODUCING A DEFECT AT THE NEUROMUSCULAR JUNCTION. EARLIER STUDIES HAVE SHOWN THAT A CONTINUOUS FREQUENCY OF 50 C.P.S. RESULTS IN AN EARLY BREAKDOWN OF THE TRANSMISSION OF THE NERVE IMPULSE TO THE MUSCLE MEMBRANE I.E. ACROSS THE NEUROMUSCULAR JUNCTION. AT A FREQUENCY OF 25 C.P.S. THIS BREAKDOWN IS NOT MARKED FOR A PERIOD OF 40-60 SECONDS AND INITIALLY PRODUCES 75-95% OF THE TETANIC TENSION. CONSEQUENTLY IF THE NEUROMUSCULAR APPARATUS AND/OR THE CONTRACTILE MECHANISM OF A MUSCLE IS MALFUNCTIONING, THE DEFECT SHOULD BECOME EVIDENT WITHIN THIS PERIOD OF TIME.

C. RELIABILITY (TABLE II)

1. GRIP TENSION. A NUMBER OF INVESTIGATORS HAVE FOUND IT IS NOT POSSIBLE TO OBTAIN HIGHLY SIGNIFICANT RELIABILITIES OF THE MEASUREMENT OF MAXIMUM STRENGTH (6, 9, 13, 24). AS MULLER EXPLAINS IN HIS EXPERIENCE THAT:

> "THE MEASUREMENT OF THE MAXIMUM STRENGTH BY VOLUNTARY MAXIMAL CONTRACTIONS OF MUSCLES IS NOT ONLY A TECHNICAL BUT ALSO A PSYCHOLOGICAL PROBLEM." (24:303)

IN ORDER TO DETERMINE THE REASONS FOR THE COMPARATIVELY LOW RELIABILITY ($R = .694$), SIX OF THE SUBJECTS WERE ASKED TO COME BACK AFTER THE EXPERIMENT WAS COMPLETED TO FURTHER TEST THE RELIABILITY OF THE RACE COMPLEX. EACH SUBJECT WAS TESTED THREE SEPARATE TIMES FOR GRIP TENSION, TETANIC TENSION AND MERTON'S TENSION AS PREVIOUSLY DESCRIBED. AFTER THE COMPLETION OF EACH TRIAL THE SUBJECT WAS RELEASED FROM THE RACE COMPLEX; HE ROSE UP FROM THE BED, AND TWO MINUTES LATER HIS ARM WAS AGAIN PLACED AND CLAMPED INTO THE SPLINT.

THE RESULTS (TABLE VIII) SHOW THAT FOR A GIVEN TIME OF DAY EACH SUBJECT

HAD ALMOST IDENTICAL SCORES FOR ANY ONE OF THE THREE AFOREMENTIONED MEASURES ON THREE SEPARATE BUT SUCCESSIVE TRIALS. IT MAY BE CONCLUDED FROM THESE DATA THAT THE RACE COMPLEX AND THE EXPERIMENTAL METHOD DID NOT CONTRIBUTE SIGNIFICANTLY TO THE LOW RELIABILITY.

A REASON FOR THIS LACK OF RELIABILITY, BESIDES THE OBVIOUS ONE OF THE SMALL NUMBER OF SUBJECTS, COULD BE THAT THE SUBJECTS WERE NOT ALLOWED TO TRAIN ON THE MECHANICAL APPARATUS BEFORE THE EXPERIMENT. BECAUSE THEY WERE NOT FAMILIAR WITH THE TESTING DEVICE, IT IS QUITE POSSIBLE THEY DID NOT KNOW HOW TO ACHIEVE THEIR MAXIMUM TENSION WITH THIS DEVICE OR WHAT HIS MAXIMUM TENSION WAS FOR THIS SPECIFIC EXERCISE.

MANY AUTHORS (26, 27, 30) HAVE SUGGESTED THAT FOR ANY MEASURE OF PHYSICAL PERFORMANCE A VERY SIGNIFICANT VARIABLE TO TAKE INTO ACCOUNT IS THE SKILL LEVEL AT WHICH THE SUBJECT PERFORMS THE EXERCISE. ALTHOUGH THE EXERCISE PER SE, IN THIS CASE, MIGHT BE CONSIDERED A VERY COMMON MOVEMENT, THE MECHANICAL DEVICE WAS COMPLETELY NEW TO MOST OF THE SUBJECTS HENCE EACH OF THEM HAD TO LEARN THROUGH TRIAL AND ERROR HOW TO ACHIEVE HIS MAXIMUM TENSION. THE MAGNITUDE OF THIS LEARNING EFFECT IN RELATION TO THE RELIABILITY SCORE OR THE T-RATIO VARIES WITH THE REQUIRED SKILL OF THE MOVEMENT WHICH INCLUDES OF COURSE THE MEASURING DEVICE. A CASE IN POINT IS THE EXERCISE PRODUCING MERTON'S TENSION. CONSIDERING THE UNUSUAL PATTERN OF THE EXERCISE THIS EFFECT MIGHT BE A VARIABLE OF MAJOR SIGNIFICANCE WHEN CORRELATING MAXIMUM STRENGTH SCORES.

2. <u>TETANIC TENSION.</u> WITH THE PSYCHOLOGICAL FACTORS SIGNIFICANTLY ELIMINATED, ONE MIGHT EXPECT A HIGHER RELIABILITY FOR TETANIC TENSION THEN THE ONE OBTAINED ($R = .884$). IN AN ATTEMPT TO EXPLAIN THIS SUPPOSED DISCREPANCY, IT COULD BE SUGGESTED THAT THE VARIABLES OF MUSCLE LENGTH AND HAND POSITION MAY INFLUENCE THE TETANIC TENSION TO A MUCH GREATER EXTENT THAN A VOLUNTARY EXERCISE BECAUSE THEY WOULD NOT BE DISGUISED BY THE INFLUENCE OF THE PSYCHOLOGICAL FACTORS ALREADY DISCUSSED IN THIS THESIS. HOWEVER THE POST-EXPERIMENTAL STUDY DOES NOT SEEM TO INDICATE THAT THESE TWO VARIABLES ARE CONTRIBUTING FACTORS. FURTHER STUDIES ARE NECESSARY TO ELUCIDATE THIS PROBLEM.

3. MERTON'S TENSION. THE SUBJECTS EXPRESSED CONCERN THAT THEY COULD NOT GIVE AN ALL OUT EFFORT WHILE CONCENTRATING ON MAINTAINING THE ANGLE OF PULL AND NOT FLEXING THE PHALANGES OF THE THUMB. PRELIMINARY STUDIES HAVE SHOWN THAT WITHIN TEN TRIALS A PERSON COULD CONCENTRATE SOLELY ON PUTTING FORTH HIS MAXIMUM EFFORT. HOWEVER THE SUBJECTS WERE NOT ALLOWED A TRAINING PERIOD BECAUSE IT WAS THOUGHT THAT THIS WOULD GREATLY DIMINISH THE EFFECTS OF THE EXERCISE PROGRAMS; ESPECIALLY WHEN THE MUSCLES UNDER INVESTIGATION WERE ALREADY IN A RELATIVELY HIGHLY TRAINED STATE. THE TRAINING CURVES FOR GROUP A SUPPORTED THIS HYPOTHESIS. IN MOST CASES THE SUBJECTS MADE THE GREATER PERCENTAGE OF THEIR GAINES WITHIN THE FIRST TWO WEEKS OF THE EXERCISE PORGRAMS.

IN ADDITION TO THE PROBLEM OF LEARNING HOW TO PERFORM THIS EXERCISE, ALL OF THE PREVIOUSLY MENTIONED PSYCHOLOGICAL VARIABLES ARE PROBABLY CONTRIBUTING TO THE LACK OF RELIABILITY ($R = .702$).

4. FATIGUE-TENSION RATIO. THE DROP IN TENSION DURING CONTINUOUS STIMULATION IS PROBABLY DUE TO A BREAKDOWN IN THE TRANSMISSION OF THE NERVE IMPULSE RATHER THAN, AS A RESULT OF THE CONTRACTILE SUBSTANCE FATIGUING IN THE MUSCLE BECAUSE THE CURVE OF THE EVOKED ACTION POTENTIAL PARALLELS THE TENSION CURVE.

BROWN AND BURNS SET OUT TO DETERMINE WHETHER THE DECLINE IN TENSION WHICH FOLLOWS PROLONGED STIMULATION OF THE MOTOR NERVE CAN BE ATTRIBUTED TO THE EXISTENCE OF NEUROMUSCULAR BLOCK. THEY DEMONSTRATED THAT ALTHOUGH THE NEUROMUSCULAR BLOCK WAS EVIDENT IT WAS NOT PERMANENT. THAT IS, A NEUROMUSCULAR JUNCTION MAY NOT RESPOND TO EVERY IMPULSE BUT RATHER A CERTAIN PERCENTAGE OF THEM DEPENDING ON THE STIMULATING FREQUENCY.

A PREVIOUS STUDY IN THIS LABORATORY NOTED THE EFFECTS OF DAILY, CONTINUOUS STIMULATION WITH SUPRAMAXIMAL SHOCKS AT A FREQUENCY OF 50 C.P.S. ON MUSCLE FATIGUE. AFTER FOUR WEEKS OF ARTIFICIAL EXERCISE, THE INITIAL AND FINAL CURVES OF BOTH THE EVOKED ACTION POTENTIAL AND THE TENSION, WHEN PLOTTED IN PERCENTAGES OF THE ORIGINAL VALUE, WERE ALMOST IDENTICAL.

THESE RESULTS WITH FEWER TRIALS WERE SUBSTANTIATED AT A FREQUENCY OF 25 C.P.S.

APPARENTLY FOR A GIVEN FREQUENCY THE RESPONSE OF THE NEUROMUSCULAR TRANSMISSION SYSTEM IS HIGHLY RELIABLE DESPITE THE OPERATION OF HIGHLY COMPLEX VARIABLES SUCH AS BLOOD CIRCULATION AND OXYGEN SUPPLY.

D. LIMITATIONS OF THE STUDY

EVERY EFFORT WAS MADE TO CONTROL THE VARIABLES WHICH MIGHT AFFECT THIS EXPERIMENT. HOWEVER THERE REMAIN A NUMBER OF IMPORTANT LIMITATIONS IN THIS STUDY.

1. NUMBER OF SUBJECTS. IT WAS EXTREMELY DIFFICULT TO OBTAIN SUBJECTS WHO WOULD VOLUNTEER TO PARTICIPATE IN THIS STUDY FOR ITS ENTIRE DURATION DUE TO THE FACT THAT THE ELECTRICAL STIMULATION WAS QUITE PAINFUL, PARTICULARLY WITH CONTINUOUS STIMULATION. AS THE MAIN PURPOSE OF THIS INVESTIGATION WAS TO DETERMINE THE EFFECTS OF REPETITIVE, TETANIC CONTRACTIONS ON MUSCLE STRENGTH AND FATIGUE, HALF OF THE EIGHTEEN SUBJECTS WERE ASKED TO BE IN GROUP A. GROUP V WAS ESTABLISHED BECAUSE AN ADDITIONAL CONTROL GROUP WAS CONSIDERED ADVISABLE TO THE DESIGN OF THE EXPERIMENT.

2. TRAINED STATE OF THE MUSCLES UNDER INVESTIGATION. FOR A VARIETY OF REASONS, THE SUBJECTS WHO TOOK PART IN THIS EXPERIMENT WERE SELECTED FROM THE STAFF OF THE REHABILITATION DEPARTMENT AT THE UNIVERSITY HOSPITAL. THE MAIN LIMITATION HERE IS THAT BECAUSE OF THE NATURE OF THEIR WORK THE HAND MUSCLES OF THESE SUBJECTS ARE MORE LIKELY TO BE IN A HIGHLY TRAINED STATE FOR BOTH MUSCLE STRENGTH AND MUSCULAR ENDURANCE WHEN COMPARED TO THE MAJORITY OF THE OTHER HEALTHY ADULTS; THEREFORE, IT WAS THOUGHT THAT THE EXERCISE PROGRAMS, BY EITHER A DAILY TETANIC CONTRACTION OR A DAILY MAXIMUM VOLUNTARY ISOMETRIC CONTRACTION, MIGHT NOT BE OF SUFFICIENT INTENSITY TO RESULT IN ANY CHANGE IN THE MUSCLES UNDER INVESTIGATION. IN AN EFFORT TO MINIMIZE THIS LIMITATION THE NON-DOMINANT HAND WAS EXERCISED.

3. EXERCISE PROGRAMS. NO OTHER PREVIOUS REPORTED STUDY HAS BEEN CONCERNED WITH THE EFFECTS OF REPETITIVE ELECTRICAL STIMULATION ON MUSCLE STRENGTH IN SUCH DEFINITIVE TERMS, CONSEQUENTLY EXERCISE PROGRAMS WERE CHOSEN WHICH WOULD

ALLOW US TO COMPARE OUR RESULTS WITH THOSE OF OTHER INVESTIGATORS. ALSO EXERCISE REGIMES CONSISTING OF ONLY A SINGLE DAILY CONTRACTION PROVIDED A GOOD AND NECESSARY BASE FOR FUTURE EXPERIMENTS.

E. EFFECTS OF ARTIFICIAL EXERCISE

1. GRIP TENSION. SINCE GROUP A INCREASED SIGNIFICANTLY IN BOTH TETANIC AND GRIP TENSION, IT IS TEMPTING TO SUGGEST THAT THE INCREASE IN GRIP TENSION IS MAINLY DUE TO THE INCREASE IN STRENGTH OF THE ULNAR SUPPLIED MUSCLES. THIS DOES NOT APPEAR TO BE THE CASE BECAUSE THE SIZE OF THE GAINS EACH SUBJECT DEMONSTRATED IN TETANIC TENSION DOES NOT CORRELATE WITH THE MAGNITUDE OF INCREASE HE HAS SHOWN FOR THE GRIP TENSION. TAKING INTO ACCOUNT THE FACT THAT NO OTHER MUSCLES BESIDES THE ULNAR SUPPLIED MUSCLES WERE EXERCISED, THE QUESTION WHICH IS IMMEDIATELY ASKED IS WHERE ARE THE ANATOMICAL LOCATIONS THAT ARE RESPONSIBLE FOR THIS INCREASE IN STRENGTH. A CONSIDERABLE NUMBER OF AUTHORS HAVE COMMENTED ON WHETHER THE IMPROVEMENTS IN STRENGTH RESULTING FROM REGULAR EXERCISE WERE PERIPHERAL, IN THE MUSCLE PERSE, OR CENTRAL IN NATURE.

(1) LEARNING - HELLEBRANDT IN DISCUSSING THE OVERLOAD PRINCIPLE OF MUSCLE TRAINING IN MAN POINTS OUT THE POSSIBLE ROLE OF THE CENTRAL NERVOUS SYSTEM IN THE TRAINING PROCESS BY STATING:

> "THE CENTRAL NERVOUS SYSTEM IS IMPLICATED JUST AS CRITICALLY AS THE PERIPHERAL TISSUES WHICH CONTRACT SECONDARILY AND PRODUCE THE MECHANICAL ENERGY USED FOR THE PERFORMANCE OF WORK. THUS A SIGNIFICANT PROPORTION OF THE END RESULT OF SYSTEMATIC VOLUNTARY EXERCISE IS DUE TO MOTOR LEARNING AND THIS PROCESS IS NECESSARY EVERY TIME NEW COMBINATIONS OF STRENGTH, SPEED, SKILL AND ENDURANCE ARE ENCOUNTERED." (10:282)

SOME AUTHORS HAVE TRAINED THE EXPERIMENTAL GROUP ON THE SAME DEVICE THAT WAS USED FOR TESTING (11, 24). THIS PROCEDURE HAS BEEN CRITICIZED BY PETERSEN WHO MAINTAINS THAT IT RESULTS IN A TRAINING EFFECT WHICH DISTORTS THE REAL VALUE OF THE TRAINING STIMULUS. THE MAGNITUDE OF THIS EFFECT VARIES WITH THE REQUIRED SKILL OF THE MOVEMENT AS WELL AS THE MECHANICAL DEVICE.

START AND HOLMES STUDIED THE LOCAL ISOMETRIC STRENGTH AND ENDURANCE OF THE ELBOW FLEXORS IN TWENTY FEMALE SUBJECTS. THE AUTHORS SUGGEST THAT:

> "...THE RAPID STRENGTH DEVELOPMENT SEEN IN THE FIRST WEEK OF TRAINING CAN REALLY BE AN INDICATION OF INCREASE IN NEUROLOGICAL CONTROL (SKILL) RATHER THAN PHYSIOLOGICAL HYPERTROPHY."

INCREASES IN STRENGTH FROM EIGHTY PER CENT TO NEARLY FOUR HUNDRED PER CENT WERE REPORTED BY ROSE ET AL. THESE RESULTS WERE SURPRISINGLY HIGH AS THE TRAINING STIMULUS CONSISTED OF ONLY A SINGLE MAXIMAL ISOMETRIC CONTRACTION FOR FIVE SECONDS. THE AUTHORS SUGGEST THAT:

> "INASMUCH AS THIS CONSUMED BUT FIVE SECONDS OF MAXIMAL EFFORT OF EACH SUCH ATTEMPT, IT IS ALMOST INCONCEIVABLE THAT THIS BRIEF PERIOD OF EXERCISE REPRESENTS MUSCULAR EXERCISE IN THE SENSE IN WHICH IT IS TRADITIONALLY REGARDED. AS HELLEBRANDT AND HOUTZ SUGGEST CHANGES IN THE CENTRAL NERVOUS SYSTEM RELATED TO MOTOR LEARNING ARE PROFOUND INDEED. THE PERSISTENCE OF STRENGTH AS A LEARNED ACT DOES NOT APPEAR TO BE AN IMPOSSIBLE CONCEPT." (27:162)

HISLOP ANALYZED THE QUANTITATIVE CHANGES THAT OCCUR IN HUMAN MUSCULAR STRENGTH WITH RESPECT TO FREQUENCY, DURATION AND INTENSITY OF EXERCISE. IN DISCUSSING HER RESULTS SHE APPEALS FOR A GREATER AWARENESS OF THE QUALITATIVE CHANGES IN THE NERVOUS SYSTEM THAT HAVE AN INFLUENCE ON MOTOR PERFORMANCE. HISLOP ELABORATES BY STATING:

> "IT IS THEN, A REASONABLE PREMISE THAT INDIVIDUAL DIFFERENCES IN MUSCULAR STRENGTH ARE DETERMINED NOT ONLY BY ANATOMICAL AND MORPHOLOGICAL FACTORS AS EXEMPLIFIED BY BIOCHEMICAL FEATURES OF MUSCULASKELETAL AND THE INTEGRITY OF THE CONTRACTILE FUNCTION OF MUSCLE, BUT ALSO TO A VERY CONSIDERABLE EXTENT OF NEUROPHYSIOLOGICAL FACTORS. IT IS THE SUM TOTAL OF ALL THE CHANGES IN THE NERVOUS SYSTEM WROUGHT BY REPETITIVE ACTIVITY AND PRACTICE THAT ARE HEREIN TERMED "MOTOR LEARNING"." (13:37)

(11) MOTIVATION - CHANGES IN THE MOTIVATIONAL LEVEL OF THE SUBJECT DURING THE TEST TRIAL ALTERS THE PERFORMANCE OR SCORE ACHIEVED BY THE SUBJECT. INVESTIGATORS HAVE APPROACHED THE PROBLEM OF MOTIVATION - PERFORMANCE THROUGH A WIDE VARIETY OF CHANNELS.

A NUMBER OF INVESTIGATORS HAVE ESTABLISHED THAT VOLUNTARY PERFORMANCE MAY BE ALTERED BY THE SOCIAL STRUCTURE OF THE TESTING SITUATION (7, 16, 22).

JOSENHANS NOTED THE EFFECTS OF MOTIVATION, IN THE FORM OF COMPETITION, ON THE GAIN IN MUSCLE FORCE RESULTING FROM A TRAINING PROGRAM. HE SUGGESTS THAT MOTIVATION MAY CONTRIBUTE TO THE GAIN IN TWO WAYS: (A) ELIMINATION OF INHIBITORY

MECHANISMS; (B) INCREASED MOBILIZATION OF MOTOR UNITS. IN ANSWER TO THE QUESTION HOW DOES MOTIVATION AFFECT THE MUSCLE FIBRE AND THE INCREASE IN MUSCLE FORCE JOSENHANS EXPLAINS:

> "INCREASED MOTIVATION MOST LIKELY MOBILIZES MORE MUSCLE TENSION; AND MOST OBSERVERS INDEED FOUND A SIGNIFICANT RELATIONSHIP BETWEEN TRAINING FORCE AND GAIN." (18:320)

HISLOP RECOMMENDS THAT TO OBTAIN THE MAXIMUM VOLUNTARY PERFORMANCE ONE SHOULD SELECT SUBJECTS WHO HAVE A PERSONAL INTEREST IN THE RESEARCH RATHER THAN A LARGER, MORE RANDOM GROUP. SHE APPEALS FOR GREATER COGNIZANCE OF THE ROLE OF MOTIVATION IN VOLUNTARY ACTIVITY. THE AUTHOR EMPHASIZES HER POINT BY STATING:

> "REGARDLESS OF THE EXACT NATURE OF THE SUBSTRATE MECHANISMS, IT MUST BE ACKNOWLEDGED THAT THE INDEFINABLE PROCESS OF MOTIVATION IS WHAT PERMITTED MAN TO RUN HIS FIRST FOUR-MINUTE MILE; AND WHAT HAS LED TO THE STATEMENT THAT 'RECORDS ARE MADE TO BE BROKEN'. THE DESIRE TO EXCEL, THEREFORE, SHOULD BE CONSIDERED AS ONE OF THE DETERMINING VARIABLES RESPONSIBLE FOR IMPROVEMENT IN HUMAN VOLUNTARY MUSCULAR STRENGTH. QUANTITATIVE ESTIMATES OF MOTIVATION CANNOT BE MADE, BUT THE OBSERVATIONS MADE IN THIS EXPERIMENT ILLUSTRATE THAT ITS PRESENCE CAN BE DRAMATICALLY DEMONSTRATED WHEN SUCH PERSONS ARE COMPARED WITH SUBJECTS WHO RESPOND IN THE USUAL OR 'AVERAGE' MANNER." (13:36)

AS MOTIVATION IS PARTLY CONFINED BY INDUCED INHIBITIONS, SOME WORKERS (15, 17, 28) HAVE EMPLOYED HYPNOSIS AS A METHOD TO DETERMINE THE EXTENT OF THESE INHIBITIONS.

THE MOST WIDELY QUOTED OF THESE STUDIES IS THE EXPERIMENT CARRIED OUT BY IKAI AND STEINHAUS. THEY OBSERVED THE EFFECTS OF GUN SHOTS, SHOUTING, ALCOHOL, DRUGS AND HYPNOSES ON THE TENSION OF RIGHT FOREARM FLEXORS IN A MAXIMUM EFFORT. ALTHOUGH ALL OF THE ABOVE MENTIONED INTERVENTIONS INCREASED THE SUBJECTS' PERFORMANCE IN SOME DEGREE, HYPNOSIS RESULTED IN THE GREATEST AND MOST CONSISTENT IN THE 'PSYCHOLOGIC LIMIT'. THEY CONCLUDED THAT:

> "ALL OBSERVATIONS REPORTED HERE SUPPORT THE THESIS THAT THE EXPRESSION OF HUMAN STRENGTH IS GENERALLY LIMITED BY PSYCHOLOGICALLY INDUCED INHIBITIONS." (15:156)

ROUSH REPORTED THAT AN INCREASE IN THE SCORE OF A GRIP TEST, ARM TEST, (MARTIN ARM TYPE) AND THE OVER HAND HANG WHEN THE SUBJECTS UNDER HYPNOSIS WERE GIVEN INSTRUCTIONS TO DISREGARD PAIN. THE RANGE OF THESE INCREASES VARIED; FOR EXAMPLE IN THE ARM TEST THERE WAS A 2.6 - 33.3% IMPROVEMENT.

A STUDY BY EYSENCK, CITED BY ROUSH, EXAMINED THE EFFECTS OF HYPNOSIS ON BOTH MENTAL AND PHYSICAL PERFORMANCES USING A BATTERY OF THIRTY TESTS ON TWO SUBJECTS. HE CONCLUDED THAT STRENGTH TESTS AND ANY TEST INVOLVING FATIGUE SEEMED TO SHOW A GREATER INCREASE IN PERFORMANCE THAN DID THE MENTAL-FUNCTION TESTS.

THE EVIDENCE SUPPORTS THE STATEMENT OF IKAI AND STEINHAUS THAT VOLUNTARY PERFORMANCE IN MOST CASES IS LIMITED BY PSYCHOLOGIC FACTORS RATHER THAN PHYSIOLOGIC FACTORS.

IT IS NOT POSSIBLE AT THE PRESENT TIME TO DIFFERENTIATE BETWEEN THE EFFECTS OF 'MOTOR LEARNING' AND 'MOTIVATION'. ONE CAN ONLY SPECULATE ON THE RELATIVE IMPORTANCE OF THE VARIOUS PHYSIOLOGICAL MECHANISMS INVOLVED IN INCREASING MUSCLE TENSION DURING VOLITIONAL EXERCISE. HOWEVER, THE EFFECT OF SUCH EXERCISE ON THE MUSCLE ITSELF CAN BE ACCURATELY DETERMINED BY EMPLOYING THE METHOD USED IN THIS EXPERIMENT AND DESIGNING A STUDY WITH A LARGER NUMBER OF SUBJECTS.

2. <u>TETANIC TENSION.</u> THE ADVANTAGE THIS STUDY HAS OVER PREVIOUS RESEARCH WHICH WAS CONCERNED WITH THE EFFECTS OF ELECTRICAL STIMULATION IS THAT A COMPLETELY OBJECTIVE MEASURE OF THE MAXIMUM MUSCLE TENSION COULD BE RECORDED. THEREFORE, FROM THE FINDINGS OF THIS STUDY, IT MAY BE CONCLUDED WITH REASONABLE CERTAINTY THAT THE INCREASES IN MUSCLE STRENGTH RESULTING FROM ELECTRICAL STIMULATION ARE PERIPHERAL IN NATURE, THAT IS WITHIN THE MUSCLE ITSELF. IT IS NOT WITHIN THE SCOPE OF THIS THESIS TO DISCUSS THE POSSIBLE PHYSIOLOGICAL BASIS FOR THESE CHANGES IN STRENGTH.

THE CONCLUSION THAT ARTIFICIAL EXERCISE RESULTS IN SIGNIFICANT INCREASES IN THE MAXIMUM TENSION THAT CAN BE PRODUCED BY A MUSCLE IS TO BE GIVEN ADDED EMPHASIS IN LIGHT OF THE LIMITATIONS IN THIS STUDY THAT FIRSTLY, THE MUSCLES WERE PROBABLY INITIALLY IN A HIGHLY TRAINED STATE AND SECONDLY, THAT THE EXERCISE PROGRAM WAS OF ALMOST MINIMUM INTENSITY.

THERE ARE NO OTHER STUDIES WITH WHICH THESE RESULTS CAN BE COMPARED. THE STUDY CONDUCTED BY MASSEY ET AL IS SEVERELY LIMITED BY THEIR TECHNIQUE OF STIMULATION AND ALSO BY THE FACT THAT THEY HAD NO WAY OF MEASURING THE EFFECTIVENESS OF THE STIMULUS. FROM THE DESIGN OF THE EXPERIMENT, THEIR STUDY IS SUBJECT TO

ALL OF THE VARIABLES ASSOCIATED WITH VOLUNTARY ACTIVITY.

ALTHOUGH THIS IS BUT AN EXPLORATORY STUDY, THE FACT THAT GROUP A SHOWED SIGNIFICANT INCREASES IN TETANIC TENSION IS SUFFICIENT EVIDENCE TO CAST DOUBT ON MOREHOUSE'S INHIBITION THEORY OF STRENGTH DEVELOPMENT.

UP TO THE PRESENT TIME THERE HAS BEEN LITTLE EXPERIMENTAL EVIDENCE TO SUPPORT THE CLINICAL IMPRESSION THAT THE INCREASES IN STRENGTH RESULTING FROM SYSTEMATIC EXERCISE ARE DIRECTLY RELATED TO CHANGES IN THE MUSCLE PER SE. THE POSITIVE FINDINGS IN THIS STUDY SUGGEST THAT THIS WOULD BE A VALUABLE METHOD FOR ASSESSING THE RELATIVE EFFICACY OF STRENGTHENING PROGRAMS WITH REGARD TO THEIR EFFECT ON THE MUSCLE AND ITS POTENTIAL FOR DEVELOPING TENSION. IN ADDITION, WITH A MORE SOPHISTICATED DESIGN THE SIGNIFICANCE OF THE PSYCHOLOGICAL VARIABLES PREVIOUSLY MENTIONED MAY BE MORE CLEARLY DEFINED.

3. MERTON'S TENSION. IT IS INTERESTING THAT GROUP A DID NOT DEMONSTRATE SIGNIFICANT GAINS IN MERTON'S TENSION, AFTER THEY SHOWED SIGNIFICANT IMPROVEMENTS FOR GRIP TENSION AND TETANIC TENSION. THE FACT THAT THERE WERE NOTABLE CHANGES IN THE MUSCLES THEMSELVES AS A RESULT OF THE ELECTRICAL STIMULATION AND THAT THEY DID NOT SHOW UP WITH THIS SPECIALLY DESIGNED EXERCISE ATTESTS TO THE STRENGTH OF THE PSYCHOLOGICAL VARIABLES WHICH HAVE ALREADY BEEN ELABORATED UPON; PARTICULARLY IN THE UNNATURAL MOVEMENT INVOLVED IN PRODUCING MERTON'S TENSION.

4. FATIGUE-TENSION RATIO. ANY CHANGE IN THE TETANIC TENSION OF THE MUSCLE WOULD NOT BE NOTED IN THE MEASURE OF FATIGUE-TENSION RATIO AS ANTICIPATED BECAUSE IT IS THE EFFICIENCY OF THE NEUROMUSCULAR TRANSMISSION SYSTEM AND NOT OF THE CONTRACTILE MECHANISM WHICH LARGELY DETERMINES THE FATIGUE-TENSION RATIO.

F. EFFECTS OF VOLUNTARY ISOMETRIC EXERCISES

AN EXCELLENT REVIEW OF THE LITERATURE WITH REGARD TO THE DEVELOPMENT OF MUSCULAR STRENGTH FROM THE LATE NINETEENTH CENTURY TO E. A. MULLER HAS BEEN PROVIDED BY STEINHAUS. THE FINDINGS OF HETTINGER AND MULLER IN 1953 COUPLED WITH THE RE-EMPHASIS ON PHYSICAL FITNESS HAVE RESULTED IN SCORES OF STUDIES INVESTIGATING THE DEVELOPMENT OF STRENGTH THROUGH VOLUNTARY ISOMETRIC EXERCISES.

JOSENHANS AND HOWELL HAVE MADE EXTENSIVE REVIEWS EVALUATING THE VARIOUS METHODS OF IMPROVING MUSCLE STRENGTH. FROM THE EVIDENCE THERE SEEMS TO BE LITTLE DOUBT THAT REGULAR VOLUNTARY ISOMETRIC EXERCISE INCREASES VOLITIONAL STRENGTH.

HOWEVER GROUP V DID NOT SHOW STATISTICALLY SIGNIFICANT IMPROVEMENTS IN ANY OF THE FOUR PARAMETERS MEASURED AND PROBABLY THE MAJOR REASON WAS BECAUSE THIS GROUP CONSISTED OF ONLY FIVE SUBJECTS. THIS HYPOTHESIS IS SUPPORTED BY THE FACT THAT THREE OF THE FIVE SUBJECTS IN GROUP V SHOWED (TABLE I) MARKED INCREASES IN GRIP TENSION WHILE THE REMAINING TWO SUBJECTS DEMONSTRATED NEGLIGIBLE CHANGES. THE CASE IS SIMILAR FOR TETANIC TENSION (TABLE II) WHERE ALL BUT ONE SUBJECT SHOWED INCREASES. FOR SOME UNKNOWN REASON, THE SUBJECT J. F. DROPPED MARKEDLY IN ALL OF THE THREE STRENGTH SCORES ON THE TEST DAY. THE TREND OF THESE RESULTS SUGGEST THAT WITH MORE SUBJECTS THE VOLUNTARY EXERCISE PROGRAM WOULD PROVE TO BE SIGNIFICANTLY EFFECTIVE IN INCREASING MUSCLE STRENGTH, AS MEASURED BY TETANIC TENSION.

ALTHOUGH THE AMOUNT OF TIME PER EXERCISE WAS APPROXIMATELY THE SAME FOR BOTH GROUPS A AND V, THE TENSION PRODUCED BY THE ULNAR SUPPLIED MUSCLES WAS GREATER FOR THE SUBJECTS THAT UNDERWENT ELECTRICAL STIMULATION (TABLES V AND VI). IT HAS BEEN STATED (13) THAT TWO THIRDS OF THE MAXIMUM TENSION IS ALL THAT IS NECESSARY TO PRODUCE MAXIMUM INCREASES IN VOLITIONAL STRENGTH. HOWEVER HISLOP HAS SHOWN THAT ISOMETRIC EXERCISES OF MAXIMAL INTENSITY PRODUCE MORE SIGNIFICANT IMPROVEMENTS IN MAXIMAL STRENGTH THAN ISOMETRIC EXERCISES OF EITHER SIXTY SEVEN PERCENT OR SEVENTY FIVE PER CENT OF MAXIMAL STRENGTH. MORE RESEARCH IS REQUIRED USING A METHOD SUCH AS DESCRIBED IN THIS STUDY BEFORE THESE FACTORS WILL BE FINALLY ELUCIDATED.

V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A COMPARISON OF THE EFFICACY OF DIFFERENT MUSCLE STRENGTHENING PROGRAMS IS MADE DIFFICULT BECAUSE OF THE MANY PSYCHOLOGICAL FACTORS SUCH AS MOTIVATION INVOLVED IN VOLITIONAL EXERCISE. THESE FACTORS CAN BE VIRTUALLY EXCLUDED IN ARTIFICIAL EXERCISE. WHEN PSYCHOLOGICAL FACTORS HAVE BEEN ELIMINATED, A DETAILED STUDY OF THE PHYSICAL PARAMETERS SUCH AS LOAD, DURATION AND FREQUENCY OF EXERCISE COULD BE UNDERTAKEN.

THE MOST EASILY AND EFFECTIVELY CONTROLLED ARTIFICIAL EXERCISE IS WHERE A MOTOR NERVE TO A SPECIFIC MUSCLE IS STIMULATED ELECTRICALLY. THE TENSION OF THE MUSCLE CAN BE ALTERED BY VARYING THE STIMULUS VOLTAGE AND FREQUENCY. AS NO SUCH STUDY HAS BEEN RECORDED IN MAN, THE PRESENT PROJECT WAS UNDERTAKEN TO DETERMINE IF ARTIFICIAL EXERCISE BY MEANS OF ELECTRICAL STIMULATION EFFECTS MUSCLE STRENGTH AND FATIGUE.

SPECIFICALLY THIS STUDY WAS CONCERNED WITH THE EFFECTS OF REPETITIVE, ELECTRICAL, TETANIC STIMULATION ON THE STRENGTH AND FATIGUE OF THE ULNAR INNERVATED MUSCLES OF THE NON-DOMINANT HAND IN HEALTHY ADULTS. TEN MALES AND EIGHT FEMALES VOLUNTEERED TO PARTICIPATE IN THE EXPERIMENT. THEY WERE DIVIDED INTO THREE GROUPS: A (N = 9) UNDERWENT A DAILY, SIX SECOND, TETANIC CONTRACTION; V (N= 5) EXERCISED BY DOING A DAILY, SIX SECOND, MAXIMUM, VOLUNTARY, ISOMETRIC CONTRACTION, AND C (N = 4) ACTED AS A CONTROL GROUP AND THEY CARRIED ON THEIR NORMAL EVERYDAY ACTIVITY. THE ULNAR INNERVATED MUSCLES OF THE DOMINANT HAND AS WELL AS THE NON-DOMINANT HAND OF ALL THE SUBJECTS WERE MEASURED FOR THE FOLLOWING PARAMETERS: (1) GRIP TENSION, (2) TETANIC TENSION, (3) MERTON'S TENSION, AND (4) FATIGUE-TENSION RATIO. THE MEASURES TAKEN ON THE DOMINANT HAND ACTED AS AN ADDITIONAL CONTROL GROUP.

THE SUBJECTS THAT UNDERWENT ELECTRICAL STIMULATION (GROUP A) SHOWED SIGNIFICANT INCREASES IN TWO OF THE FOUR MEASURES - GRIP TENSION AND TETANIC TENSION. GROUP V SUBJECTS, WHO UNDERWENT VOLUNTARY ISOMETRIC EXERCISE, DID NOT

DEMONSTRATE STATISTICALLY SIGNIFICANT GAINS IN ANY OF THE FOUR PARAMETERS UNDER DISCUSSION.

FROM THE FINDINGS OF THIS STUDY WE MAY CONCLUDE THAT:

1. ARTIFICIAL EXERCISE BY MEANS OF ELECTRICAL STIMULATION CAN INCREASE MUSCLE STRENGTH.
2. THE INCREASE IN MUSCLE STRENGTH FROM THIS TYPE OF EXERCISE IS PERIPHERAL IN NATURE.
3. THIS METHOD SHOULD BE OF GREAT VALUE IN COMPARING THE EFFICACY OF DIFFERENT MUSCLE STRENGTHENING REGIMES.

BECAUSE OF THE LIMITATIONS OF THIS STUDY IT WAS NOT POSSIBLE TO COMPARE THE EFFECTIVENESS OF THE VOLUNTARY AND ARTIFICIAL EXERCISE PROGRAM.

RECOMMENDATIONS:

1. FURTHER REFINE THAT PORTION OF THE MECHANICAL APPARATUS WHICH IS CONCERNED WITH MAINTAINING THE LENGTH OF THE MUSCLE.
2. OBTAIN MORE SUBJECTS AND REPEAT THE EXPERIMENT.
3. UTILIZE THE METHOD EMPLOYED IN THIS STUDY FOR INVESTIGATION OF:
   (I) STRENGTH LIMITS RELATIVE TO SPECIFIC EXERCISES.
   (II) QUANTIFYING PSYCHOLOGICAL FACTORS ASSOCIATED WITH VOLUNTARY EXERCISE.

ACKNOWLEDGEMENTS

To my loving parents, I dedicate this thesis. Their sacrifice has been long and hard. I hope it has been gratified in some small way.

The constructive criticisms made by the thesis committee are very much appreciated.

I owe a great deal of thanks to my loyal subjects; to my sister, Mrs. L. Bellavance, for typing the rough and final copies of this thesis; Mr. Maurice Carrick who so willingly and promptly filled my many requests in regard to the construction of the mechanical apparatus; and in particular, to Mr. Ed Kleebaum, the laboratory technician whose technical advice and helpful assistance carried many a day. Indeed without the contributions of these people and many more, this thesis could not have been completed.

This study is one component of a three year study on muscle fatigue sponsored by the Department of National Health and Welfare. I am also very grateful to the Polio Foundation, Alberta Chapter (Canadian Legion) for financial support in this project.

I am saving, to the last, my most especial thanks for Dr. M.T.F. Carpendale. He was not merely an advisor who was meticulous for detail, who possessed a rigid integrity towards his research and staff, and who had the ability to always give unbiased constructive criticism but most of all he was of the conviction that I should spring from his shoulders into all aspects of life. Dr. Carpendale is more of a man than anyone else I know. In him I have found a staunch friend.

VI

BIBLIOGRAPHY

BIBLIOGRAPHY

1. BIGLAND, B., LIPPOLD, O.C.J.: "MOTOR UNIT ACTIVITY IN VOLUNTARY CONTRACTION OF HUMAN MUSCLE", JOURNAL OF PHYSIOLOGY, VOL. 125: PP. 322 - 335, 1954.
2. BORDIER, H., ARCH. D'ELECTR. MED. 10:331, 1902 (QUOTED BY FISCHER, E., "THE EFFECT OF FARADIC AND GALVANIC STIMULATION UPON THE COURSE OF ATROPHY IN DENERVATED SKELETAL MUSCLES ". AMERICAN JOURNAL OF PHYSIOLOGY, VOL. 27: 605 - 619, NO. 4, 1939.)
3. BROWN, G.L., BURNS, D.B., "FATIGUE AND NEUROMUSCULAR BLOCK IN MAMMALIAN SKELETAL MUSCLE", PROCEEDINGS OF THE ROYAL SOCIETY OF LONDON: SERIES B; BIOLOGICAL SCIENCES. VOL. 136: 189 - 195, 1949.
4. DEBEDAT, F.X., ARCH. D'ELECTR. MED., 2:100, 1894 (QUOTED BY FISCHER, E. SEE REFERENCE NUMBER 2 ABOVE)
5. FERGUSON, G.A., STATISTICAL ANALYSIS IN PSYCHOLOGY AND EDUCATION. MCGRAW-HILL BOOK COMPANY, NEW YORK, 1959, PP. 138 - 9.
6. GARDINER, E.N., "ATHLETICS OF THE ANCIENT WORLD". OXFORD. CLARINDON PRESS, 1930.
7. GERDES, G.R., "THE EFFECTS OF VARIOUS MOTIVATIONAL TECHNIQUES UPON PERFORMANCE IN SELECTED PHYSICAL TESTS", MICROCARDS 158:734, BF 683, 1958. P.E.D. THESIS, INDIANA UNIVERSITY.
8. HANSEN, T.E., LINDHARD, J., "ON THE MAXIMUM WORK OF HUMAN MUSCLES ESPECIALLY THE FLEXORS OF THE ELBOW", JOURNAL OF PHYSIOLOGY, VOL. 57, 1923, PP. 287-300.
9. HANSEN, J.W., "THE EFFECT OF SUSTAINED ISOMETRIC MUSCLE CONTRACTION ON VARIOUS MUSCLE FUNCTIONS", INTERNATIONALE ZEITSCHRIFT FUR ANGEWANDTE PHYSIOLOGIE, VOL. 19, PP. 430 - 434, 1963.
10. HELLEBRANDT, F.A., "APPLICATION OF THE OVERLOAD PRINCIPLE OF MUSCLE TRAINING IN MAN", AMERICAN JOURNAL OF PHYSICAL MEDICINE, VOL. 37: 1958, PP. 278 - 283.
11. HETTINGER, T., MULLER, E.A., "MUSKELLEISTUNG UND MUSKEL-TRAINING", ARBEITSPHYSIOLOGIE, VOL. 15: 111 - 126, 1953.

12. HETTINGER, THEODOR, "PHYSIOLOGY OF STRENGTH". CHARLES C. THOMAS PUBLISHER, 1961.

13. HISLOP, H.J., "QUANTITATIVE CHANGES IN HUMAN MUSCULAR STRENGTH DURING ISOMETRIC EXERCISE", J.A.P.T.A., VOL. 43: NO. 1, PP. 21 - 38, 1963.

14. HOWELL, M.L., "THE DEVELOPMENT OF STRENGTH AND MUSCULAR ENDURANCE BY ISOMETRIC CONTRACTIONS", PROCEEDINGS OF THE THIRD BRITISH EMPIRE AND COMMONWEALTH CONFERENCE ON PHYSICAL EDUCATION, THE UNIVERSITY OF WESTERN AUSTRALIA, PERTH, NOV. 15 - 21, 1962.

15. IKAI, M., STEINHAUS, A.H., "SOME FACTORS MODIFYING THE EXPRESSION OF HUMAN STRENGTH", HEALTH AND FITNESS IN THE MODERN WORLD. PP. 148 - 161, 1961.

16. JOHNSON, B.L., "INFLUENCES OF PUBERAL DEVELOPMENT ON RESPONSES TO MOTIVATED EXERCISES", RESEARCH QUARTERLY, VOL. 27: 1956, PP. 182 - 193.

17. JOHNSON, W.R., KRAMER, F.G., "EFFECTS OF STEREOTYPED NONHYPNOTIC, HYPNOTIC AND POSTHYPNOTIC SUGGESTIONS UPON STRENGTH, POWER AND ENDURANCE", RESEARCH QUARTERLY, VOL. 32: 1961, PP. 522 - 529.

18. JOSENHANS, W.K.T., "AN EVALUATION OF SOME METHODS OF IMPROVING MUSCLE STRENGTH". REVUE CANADIENNE DE BIOLOGIE, VOL. 21: NOS. 3 ET 4, 1962, PP. 315 - 322.

19. LINDSLEY, D.B., "ELECTRICAL ACTIVITY OF HUMAN MOTOR UNITS DURING VOLUNTARY CONTRACTION". AMERICAN JOURNAL OF PHYSIOLOGY, VOL. 114: 1935, PP. 90 - 99.

20. MASSEY, B.H., NELSON, R.C., OTTOT, G., SHARKEY, B.J., "THE EFFECT OF INVOLUNTARY TRAINING WITH HIGH FREQUENCY ELECTRICAL STIMULATION UPON STRENGTH AND MUSCLE SIZE". SCHEDULED FOR PUBLICATION IN THE JOURNAL OF SPORTS MEDICINE AND PHYSICAL FITNESS, AN ABSTRACT OF THIS STUDY APPEARS IN THIS JOURNAL, VOL. 4:3, SEPT., P. 186, 1964.

21. MERTON, P.A., "VOLUNTARY STRENGTH AND FATIGUE". JOURNAL OF PHYSIOLOGY, VOL. 123: MARCH, 1954, PP. 553 - 564.

22. MISSUIRO, W., "EMOTIONS AND HUMAN PERFORMANCE". HEALTH AND FITNESS IN THE MODERN WORLD, 1961, PP. 199 - 206.

23. MOREHOUSE, L., "PHYSIOLOGICAL BASIS OF STRENGTH DEVELOPMENT". UNIVERSITY OF ILLINOIS PRESS, 1960.

24. MULLER, E.A., "PHYSIOLOGY OF TRAINING". REVUE CANADIENNE DE BIOLOGIE, VOL. 21: 1962, NOS. 3 ET 4, PP. 303 - 313.

25. NOWAKAWSKA, A., "EFFECT OF EXPERIMENTAL MUSCULAR TRAINING PRODUCED BY ELECTRICAL STIMULATION". ACTA PHYSIOLOGICA POLONICA, 13:77, 1962, CITED BY MASSEY ET AL NO. 20 IN THIS BIBLIOGRAPHY.

26. PETERSEN, B., "MUSCLE TRAINING BY STATIC CONCENTRIC AND ECCENTRIC CONTRACTIONS". ACTA PHYSIOLOGICA SCANDINAVICA, VOL. 48: 1960, PP. 406 - 416.

27. ROSE, DONALD L., RADZYMINSKI, STANLEY F., BEATTY, RALPH R., "EFFECT OF BRIEF MAXIMAL EXERCISE ON THE STRENGTH OF THE QUADRICEPS FEMORIS". ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION, VOL. 38: MARCH, 1957, PP. 157-164.

28. ROUSH, E.S., "STRENGTH AND ENDURANCE IN THE WAKING AND HYPNOTIC STATES". JOURNAL OF APPLIED PHYSIOLOGY, VOL. 3: JAN., 1951, PP. 404 - 410.

29. ROWNTREE, T., "ANOMALOUS INNERVATION OF THE HAND MUSCLES". THE JOURNAL OF BONE AND JOINT SURGERY, VOL. 31 B: 505 - 510, 1949.

30. START, K.B., HOLMES, R., "LOCAL MUSCLE ENDURANCE WITH OPEN AND OCCLUDED INTRAMUSCULAR CIRCULATION". JOURNAL OF APPLIED PHYSIOLOGY, VOL. 18, JULY, 1963, PP. 804 - 7.

31. STEINHAUS, A.H., "STRENGTH FROM MOPURGO TO MULLER - A HALF CENTURY OF RESEARCH". PHYSICAL MEDICINE AND REHABILITATION. VOL. 9:5, SEPT. - OCT., 1955, PP. 147 - 150.

VII

TABLES

TABLE I

SAMPLE CALCULATION OF RELIABILITY COEFFICIENT*

TETANIC TENSION

SUBJECT	GRIP TEST I X_1	TENSION (LBS.) TEST II X_2	$(X_1)^2$	$(X_2)^2$	X_1X_2
J.S.	13.6	14.7	185.0	216.1	200.0
D.J.	18.9	16.5	357.2	272.3	311.9
J.F.	13.1	15.0	171.6	225.0	196.5
D.K.	20.3	16.6	412.1	275.6	337.0
D.Q.	13.2	14.8	174.2	219.0	195.4
S.M.	12.2	11.6	148.8	134.6	141.5
R.W.	12.5	12.5	156.3	156.3	156.3
H.S.	11.1	12.8	123.2	163.8	142.1
G.P.	10.6	9.0	112.4	81.0	95.4
E.E.	11.9	12.4	141.6	153.8	147.6
M.C.	14.1	16.1	198.8	259.2	227.0
E.K.	21.0	20.0	441.0	400.0	420.0
V.M.	19.3	19.3	372.5	372.5	372.5
DR. C.	15.8	15.2	249.6	241.0	240.2
N = 14	SUM $-\Sigma X_1$ = 207.6	ΣX_2 = 206.5	$\Sigma(X_1)^2$ = 3,244.3	$\Sigma(X_2)^2$ = 3,160.3	ΣX_1X_2 = 3,183.4
	MEAN $(\overline{X_1})$ = 14.83	$\overline{X}_2$ = 14.75	$\overline{(X_1)^2}$ = 231.74	$\overline{(X_2)^2}$ = 225.72	$\overline{X_1X_2}$ = 227.36

COMPUTATION:

VARIANCE

$$(S.D._{X_1})^2 = \overline{(X_1)^2} - (\overline{X_1})^2$$
$$= 231.74 - (14.83)^2$$
$$= 231.74 - 219.93$$
$$= 11.81$$
$$S.D._{X_1} = \sqrt{11.81} = \underline{3.44}$$

$$(S.D._{X_2})^2 = \overline{(X_2)^2} - (\overline{X}_2)^2$$
$$= 225.72 - (14.75)^2$$
$$= 225.72 - 217.56$$
$$= 8.16$$
$$S.D._{X_2} = \sqrt{8.16} = \underline{2.85}$$

$$r_{X_1X_2} = \frac{(\overline{X_1X_2}) - (\overline{X}_1 \cdot \overline{X}_2)}{(S.D._{X_1})\ (S.D._{X_2})}$$

$$= \frac{227.36 - (14.83 \times 14.75)}{(3.44)\qquad(2.85)}$$

$$r_{X_1X_2} = \frac{227.36 - 218.7}{9.8}$$

$$r_{X_1X_2} = \frac{8.66}{9.8}$$

$$r_{X_1X_2} = \underline{.884}$$

*THE FORMULA USED FOR THE COMPUTATION OF THE RELIABILITY COEFFICIENT IS EQUIVALENT TO THAT FOUND IN: PSYCHOLOGICAL STATISTICS, QUINN MCNEMAR, JOHN WILEY AND SONS, INC. NEW YORK, 1962, PAGE 112.

TABLE II

RELIABILITY SCORES* OF SUBJECTS FOR TEST I AND TEST II

SUBJECT	GRIP TENSION		TETANIC TENSION		MERTON'S TENSION		FATIGUE-TENSION RATIO	
	TEST I	TEST II	TEST I	TEST II	TEST I	TEST II	TEST I	TEST II
J.S.	20.2	----	13.6	14.7	15.8	17.0	0.291	0.405
D.J.	34.2	29.4	18.9	16.5	26.7	20.0	0.378	0.408
J.F.	23.3	25.2	13.1	15.0	15.2	15.5	0.30	0.333
D.K.	32.1	25.0	23.0	16.6	21.2	15.8	0.329	0.453
D.Q.	30.3	34.5	13.2	14.8	16.1	21.0	0.44	0.44
S.M.	26.0	26.7	12.2	11.6	15.4	13.2	0.306	0.31
R.W.	25.4	23.1	12.5	12.5	14.0	11.9	0.242	0.34
H.S.	24.4	23.8	11.1	12.8	13.6	13.9	0.39	0.45
G.P.	23.6	23.6	10.6	9.0	12.8	10.0	0.195	0.27
E.E.	27.2	24.4	11.9	12.4	14.1	19.5	0.465	0.555
M.C.	30.4	31.6	14.1	16.1	24.0	25.8	0.232	0.30
E.K.	34.2	36.6	21.0	20.0	22.6	23.0	0.204	0.288
V.M.	35.3	35.2	19.3	19.3	19.3	19.6	-----	-----
DR.C.	24.0	30.6	15.8	15.2	18.5	16.8	-----	-----
	N = 13	R= .694	N = 14	R= .884	N = 14	R= .704	N = 12	R= .960

* ALL VALUES EXPRESSED IN POUNDS.

TABLE III

SAMPLE CALCULATION OF T-RATIO*

ARTIFICIAL TRAINING GROUP

SUBJECT	GRIP TENSION (LBS.) INITIAL TEST	FINAL TEST	DIFFERENCE	SQUARE OF DIFFERENCE
H.S.	23.8	25.6	1.8	3.24
E.E.	24.4	28.1	3.7	13.69
S.M.	26.7	26.6	0.1	0.01
M.C.	31.6	33.1	1.5	2.25
E.K.	36.6	42.5	5.9	34.8
DR.C.	30.6	37.0	6.4	40.96
R.W.	23.1	26.6	3.5	12.25
V.M.	35.2	37.6	2.4	5.76
G.P.	23.6	25.0	1.4	1.96
N = 9		TOTAL	26.7	114.93
		MEAN	2.94	

TEST OF SIGNIFICANCE:

$$S_D^2 = \frac{\Sigma D^2}{N} - (\bar{D})^2$$

$$= \frac{114.93}{9} - (2.94)^2$$

$$= 12.77 - 8.64$$

$$S_D^2 = 4.13$$

$$t = \frac{\bar{D}}{\sqrt{S_D^2 / N-1}} \qquad t = \frac{2.94}{\sqrt{.51}}$$

$$= \frac{2.94}{\sqrt{4.13 / 8}} \qquad t = \frac{2.94}{.71} \qquad t = 4.14$$

* THE FORMULA USED FOR THE COMPUTATION WAS TAKEN FROM: "SIGNIFICANCE OF THE DIFFERENCE BETWEEN TWO MEANS FOR CORRELATED SAMPLES" - FERGUSON, G.A., STATISTICAL ANALYSIS IN PSYCHOLOGY AND EDUCATION, MCGRAW-HILL BOOK CO., NEW YORK, 1959, PP. 138, 139.

TABLE IV

A COMPARISON OF THE DIFFERENCE OF GRIP TENSION IN EXERCISED AND NON-EXERCISED HANDS IN THREE GROUPS OF SUBJECTS AFTER FIVE WEEKS OF EXERCISE

					EXERCISED HAND					NON-EXERCISED HAND (CONTROL)					
					GRIP TENSION (LBS.)			SQUARE OF		GRIP TENSION (LBS.)			SQUARE OF		
GROUP	NO.	SUBJECT	SEX	AGE	INITIAL+ TEST	FINAL TEST	DIFF. (D)	DIFFERENCE	T-RATIO	INITIAL++ TEST	FINAL TEST	DIFF. (D_C)	DIFFERENCE	T-RATIO	D-D_C
ARTIFICIAL EXERCISE	1	H.S.	F	22	23.8	25.6	1.8	3.24		26.0	19.6	-5.4	29.16		7.2
	2	E.E.	F	23	24.4	28.1	3.7	13.69		24.2	24.4	0.2	0.04		3.5
	3	S.M.	F	22	26.7	26.6	0.1	0.01		24.9	26.2	1.3	1.69		-1.4
N = 9	4	M.C.	M	34	31.6	33.1	1.5	2.25		28.7	34.0	5.3	28.09		-3.8
	5	E.K.	M	29	36.6	42.5	5.9	34.81		33.4	28.4	-5.0	25.0		10.9
	6	DR.C.	M	39	30.6	37.0	6.4	40.96		22.5	28.6	6.1	37.21		0.3
	7	R.W.	F	22	23.1	26.6	3.5	12.25		24.4	24.6	0.2	0.04		3.3
	8	V.M.	M	24	35.2	37.6	2.4	5.76		26.3	33.4	7.1	50.41		-4.7
	9	G.P.	F	22	23.6	25.0	1.4	1.96		15.2	22.0	6.8	46.24	1.15	-5.4
			TOTAL		255.6	282.1	26.7	114.93	4.14*	225.6	241.2	16.6	217.88		
			MEAN		28.4	31.34	2.94			25.06	26.8	1.84			
			S.D.DIFF.				1.99					4.59			
VOLUNTARY EXERCISE	10	J.F.	F	22	23.3	22.5	-0.8	0.64		17.0	17.7	0.7	0.49		-1.34
	11	D.K.	M	27	25.0	34.5	9.5	90.25		31.0	33.0	2.0	4.0		7.5
	12	D.J.	M	22	29.4	32.8	3.4	11.56		37.4	38.3	0.9	0.81		2.5
N = 5	13	D.Q.	M	22	34.5	33.4	-0.9	0.81		29.7	29.4	-0.3	0.09		-0.6
	14	J.S.	F	24	20.2	28.2	8.2	67.24		25.0	33.6	8.6	72.96		-0.4
			TOTAL		132.4	151.4	19.4	170.50	1.80	140.1	152.0	11.9	79.35		
			MEAN		26.48	30.28	3.91			28.02	30.4	2.38		1.50	
			S.D.DIFF.				4.3					3.1			
CONTROL	15	J.L.	M	45	26.2	33.0	6.8	46.24		20.3	29.2	8.9	79.21		
	16	DR.W.	M	38	34.8	41.5	6.7	44.89		39.6	39.6	0	0		
N = 4	17	J.F.	M	45	40.0	31.1	-8.9	79.21		33.0	33.7	0.7	0.49		
	18	E.Z.	M	32	36.2	41.0	4.8	23.04							
			TOTAL		137.2	146.6	9.4	193.38	0.64	92.9	102.5	9.6	79.70	1.01	
			MEAN		34.3	36.65	2.35			30.73	34.16	3.1			
			S.D.DIFF.				4.7					4.0			

* SIGNIFICANT AT 0.01 LEVEL OF CONFIDENCE.

\+ SCORE ACHIEVED ON THE SECOND PRE-EXPERIMENTAL TEST.

++ SCORE ACHIEVED ON THE FIRST PRE-EXPERIMENTAL TEST.

TABLE V

A COMPARISON OF THE DIFFERENCE OF TETANIC TENSION IN EXERCISED AND NON-EXERCISED HANDS IN THREE GROUPS OF SUBJECTS AFTER FIVE WEEKS OF EXERCISE

					EXERCISED HAND					NON-EXERCISED HAND (CONTROL)				
					TETANIC TENSION (LBS.)			SQUARE OF		TETANIC TENSION (LBS.)			SQUARE OF	
GROUP	NO.	SUBJECT	SEX	AGE	INITIAL+ TEST	FINAL TEST	DIFF. (D)	DIFFERENCE	T-RATIO	INITIAL++ TEST	FINAL TEST	DIFF. (D_C)	DIFFERENCE	T-RATIO $D-D_C$
ARTIFICIAL EXERCISE	1	H.S.	F	22	12.8	15.2	2.4	5.76		12.2	10.1	-2.1	4.41	4.5
	2	E.E.	F	23	12.4	12.9	0.5	0.25		15.2	16.0	0.8	0.64	-0.3
	3	S.M.	F	22	11.6	14.4	2.8	7.84		13.8	15.0	1.2	1.44	1.6
N = 9	4	M.C.	M	34	16.1	18.1	2.0	4.00		19.4	19.4	0	0	2.0
	5	E.K.	M	29	20.0	24.0	4.0	16.00		23.7	24.2	0.5	0.25	3.5
	6	DR.C.	M	39	15.2	16.2	1.0	1.00		15.3	17.0	1.7	2.89	-0.7
	7	R.W.	F	22	12.5	13.3	0.8	0.64		13.1	13.1	0	0	0.8
	8	V.M.	M	24	19.3	20.4	1.1	1.21		23.0	24.2	1.2	1.44	-0.1
	9	G.P.	F	22	9.0	9.8	0.8	0.64		11.7	15.9	4.2	17.64	-3.4
			TOTAL		128.9	144.3	15.4	37.34	4.39*	147.4	154.9	7.5	28.71	1.48
			MEAN		14.32	16.03	1.71			16.37	17.2	0.83		
			S.D.DIFF.				1.1					1.5		
VOLUNTARY EXERCISE	10	J.F.	F	22	15.0	10.4	-4.6	21.16		15.5	13.5	-2.0	4.0	-2.6
	11	D.K.	M	27	16.6	22.2	5.6	31.36		24.5	23.2	-1.3	1.69	6.9
	12	D.J.	M	22	16.5	21.2	4.7	22.09		23.0	25.4	2.4	5.76	-2.3
N = 5	13	D.Q.	M	22	14.8	15.5	0.7	0.49		16.8	18.3	1.5	2.25	-0.8
	14	J.S.	F	24	14.7	19.5	4.8	23.04		22.6	24.8	2.2	4.84	2.6
			TOTAL		77.6	88.8	11.2	98.14	1.17	102.4	105.2	2.8	18.54	0.60
			MEAN		15.5	17.7	2.24			20.48	21.2	0.56		
			S.D.DIFF.				3.6					1.9		
CONTROL	15	J. L.	M	45	13.5	12.3	-1.2	1.44		13.4	13.0	-0.4	0.16	
	16	DR.W.	M	38	18.8	18.3	-0.5	0.25		19.0	18.3	-0.7	0.49	
N = 4	17	J.F.	M	45	20.0	24.2	4.2	17.64		19.7	17.7	-2.0	4.00	
	18	E.Z.	M	32	22.0	23.2	1.2	1.44						
			TOTAL		74.3	78.0	4.7	20.77	1.06	52.1	49.0	-3.1	4.65	2.10
			MEAN		18.57	19.5	1.17			14.03	16.3	-1.03		
			S.D.DIFF.				1.80					2.1		

* SIGNIFICANT AT 0.01 LEVEL OF CONFIDENCE.

\+ SCORE ACHIEVED ON THE SECOND PRE-EXPERIMENTAL TEST.

++ SCORE ACHIEVED ON THE FIRST PRE-EXPERIMENTAL TEST.

TABLE VI

A COMPARISON OF THE DIFFERENCE OF MERTON'S TENSION IN EXERCISE AND NON-EXERCISED HANDS IN THREE GROUPS OF SUBJECTS AFTER FIVE WEEKS OF EXERCISE

					EXERCISED HAND					NON-EXERCISED HAND (CONTROL)					
					MERTON'S TENSION (LBS.)			SQUARE OF		MERTON'S TENSION (LBS.)			SQUARE OF	T-	
GROUP	NO.	SUBJECT	SEX	AGE	INITIAL+ TEST	FINAL TEST	DIFF. (D)	DIFFERENCE	T-RATIO	INITIAL++ TEST	FINAL TEST	DIFF. (D_C)	DIFFERENCE	RATIO	$D-D_C$
ARTIFICIAL	1	H.S.	F	22	13.9	14.2	0.3	0.09		13.5	10.3	-2.2	4.84		2.5
EXERCISE	2	E.E.	F	23	19.5	15.0	-4.5	20.25		16.2	14.8	-1.4	1.96		-3.1
	3	S.M.	F	22	13.2	15.8	2.6	6.76		12.4	16.2	3.8	14.44		-1.2
N = 9	4	M.C.	M	34	25.8	24.6	-0.8	0.64		25.0	20.0	-5.0	25.00		4.2
	5	E.K.	M	29	23.0	26.0	-0.3	0.09		24.0	26.4	2.4	5.76		-2.7
	6	DR.C.	M	39	16.8	20.2	3.4	11.56		19.8	17.2	-2.6	6.76		6.0
	7	R.W.	F	22	11.9	15.1	3.2	10.24		10.3	12.9	2.6	6.76		5.8
	8	Y.M.	M	24	19.6	16.4	-3.2	10.24		20.8	22.5	1.7	2.89		-4.9
	9	G.F.	F	22	10.0	9.8	-0.2	0.04		9.5	11.4	1.9	3.61		-2.1
			TOTAL		153.7	157.1	0.5	59.91	0.06	151.6	151.7	1.2	72.02	0.50	
			MEAN		17.08	17.46	0.056			16.73	16.74	0.133			
			S.D.DIFF.				1.6					1.6			
VOLUNTARY	10	J.F.	F	22	15.5	10.5	-5.0	25.0		13.6	12.3	-1.3	1.69		-3.7
EXERCISE	11	D.K.	M	27	15.8	23.5	7.7	59.29		25.1	26.4	1.3	1.69		6.4
	12	D.J.	M	22	20.0	24.2	4.2	17.64		22.2	29.8	7.6	57.76		-3.4
N = 5	13	D.Q.	M	22	21.0	18.6	-2.4	5.76		19.7	20.2	0.5	0.25		-2.9
	14	J.S.	F	24	17.0	21.4	3.4	11.56		21.5	22.4	0.9	8.81		2.3
			TOTAL		89.3	98.2	7.9	119.25	0.63	102.1	111.1	9.0	72.20	1.15	
			MEAN		17.86	19.64	1.58			20.42	22.2	1.8			
			S.D.DIFF.				4.6					3.0			
CONTROL	15	J.L.	M	45	14.7	12.7	-2.0	4.0		17.5	17.4	-0.1	0.01		
	16	DR.W.	M	38	19.7	21.2	1.5	2.25		20.6	21.6	1.0	1.0		
N = 4	17	J.F.	M	45	23.7	22.2	-1.5	2.25		22.4	25.4	3.0	9.0		
	18	E.Z.	M	32	21.0	20.6	-0.4	0.16							
			TOTAL		79.1	76.7	0.6	8.66	0.18	60.5	64.4	3.90	10.01	1.44	
			MEAN		19.77	19.1	0.15			20.16	21.46	1.30			
			S.D.DIFF.				1.5					1.3			

+ SCORE ACHIEVED ON THE SECOND PRE-EXPERIMENTAL TEST.

++ SCORE ACHIEVED ON THE FIRST PRE-EXPERIMENTAL TEST.

TABLE VII

A COMPARISON OF THE DIFFERENCE IN FATIGUE-TENSION RATIO IN EXERCISE AND NON-EXERCISED HANDS IN THREE GROUPS OF SUBJECTS AFTER FIVE WEEKS OF EXERCISE

					EXERCISED HAND					NON-EXERCISED HAND (CONTROL)				
GROUP	NO.	SUBJECT	SEX	AGE	FATIGUE-TENSION RATIO* INITIAL+ TEST	FINAL TEST	DIFF. (D)	SQUARE OF DIFFERENCE	t-RATIO	FATIGUE-TENSION RATIO INITIAL++ TEST	FINAL TEST	DIFF. (D_C)	SQUARE OF DIFFERENCE	t-RATIO	$D-D_C$
ARTIFICIAL EXERCISE	1	H.S.	F	22	0.34					0.37					
	2	E.E.	F	23	0.27	0.445	0.175	0.0322		0.328	0.380	0.052	0.0025		0.123
	3	S.M.	F	22	0.44	0.396	-0.044	0.0019		0.48	0.53	0.05	0.0025		-0.049
N = 9	4	M.C.	M	34	0.555	0.51	-0.045	0.0020		0.585	0.46	-0.129	0.0169		0.084
	5	E.K.	M	29	0.30	0.272	-0.028	0.0009		0.405	0.364	-0.041	0.0016		0.013
	6	DR.C.	M	39	0.198	0.325	0.127	0.016		0.43	0.395	-0.035	0.0016		0.162
	7	R.W.	F	22	0.31	0.395	0.085	0.0008		0.181					
	8	V.M.	M	24	0.288	0.228	-0.06	0.0004		0.284	0.204	-0.08	0.0064		0.02
	9	G.P.	F	22	0.45	0.42	-0.03	0.0009		0.41	0.52	0.11	0.0121		-0.14
			TOTAL		3.151	2.971	0.180	0.0549	0.75	3.473	2.855	-0.073	0.0436	0.30	
			MEAN		0.350		0.0225	0.0004		0.385	0.408	-0.0102			
			S.D.DIFF.				0.085					0.07			
VOLUNTARY EXERCISE	10	J.F.	F	22	0.333					0.421	0.415	-0.006	0.0000		
	11	D.K.	M	27	0.453	0.42	-0.033	-0.0009		0.428	0.415	-0.013	0.0001		-0.02
	12	D.J.	M	22	0.408	0.314	-0.094	-0.0008		0.517	0.418	-0.099	0.011		0.005
N = 5	13	D.Q.	M	22	0.372	0.552	0.180	0.032		0.557	0.359	-0.198	0.039		0.378
	14	J.S.	F	24	0.405					0.535					
			TOTAL		1.971	1.286	0.053	0.0337	0.24	2.458	1.607	-0.316	-0.0491	1.60	
			MEAN		0.394	0.428	0.017			0.491	0.402	-0.074			
			S.D.DIFF.				0.11					0.075			
CONTROL	15	J.L.	M	45	0.37					0.483					
	16	DR.W.	M	38	0.294	0.191	-0.103	-0.010		0.311	0.384	-0.073	0.0049		
N = 4	17	J.F.	M	45	0.307	0.363	-0.056	-0.0036		0.387	0.246	-0.141	-0.0196		
	18	E.Z.	M	32						0.387	0.467	-0.08	0.0064		
			TOTAL		0.971	0.554	-0.047	0.0136	0.29	1.568	1.097	-0.06	0.0309	0.28	
			MEAN		0.242	0.277	-0.023			0.392	0.366	-0.02			
			S.D.DIFF.				0.08					0.01			

* Fatigue-Tension Ratio Is The Tetanus After Two Minutes Of Continuous Stimulation At a Frequency Of 25 c.p.s. Divided By The Maximum Tetanus Tension On Initial Stimulation At The Same Frequency.

\+ Score Achieved On The Second Pre-experimental Test.

++ Score Achieved On The First Pre-experimental Test.

TABLE VIII

RESULTS OF POST-EXPERIMENTAL TEST ON THREE
SUCCESSIVE BUT SEPARATE TRIALS OF
GRIP TENSION, TETANIC TENSION, AND MERTON'S TENSION

SUBJECT	TRIAL	GRIP TENSION	TETANIC TENSION	MERTON'S TENSION
S.M.	1	24.2	12.3	12.8
	2	23.8	13.0	12.8
	3	23.6	12.6	12.1
M.C.	1	36.2	16.9	22.4
	2	36.2	16.0	21.6
	3	34.2	15.8	20.8
E.K.	1	39.6	22.6	23.1
	2	39.0	22.2	20.5
	3	36.3	22.0	22.6
DR.C.	1	40.5	15.0	17.9
	2	41.0	15.2	16.2
	3	38.2	15.0	15.2
R.W.	1	27.0	14.4	14.1
	2	26.6	14.1	14.1
	3	26.0	13.7	13.4
V.M.	1	37.2	19.2	19.4
	2	37.6	20.0	18.5
	3	39.2	20.0	19.2

ALL VALUES EXPRESSED IN POUNDS

FIGURES

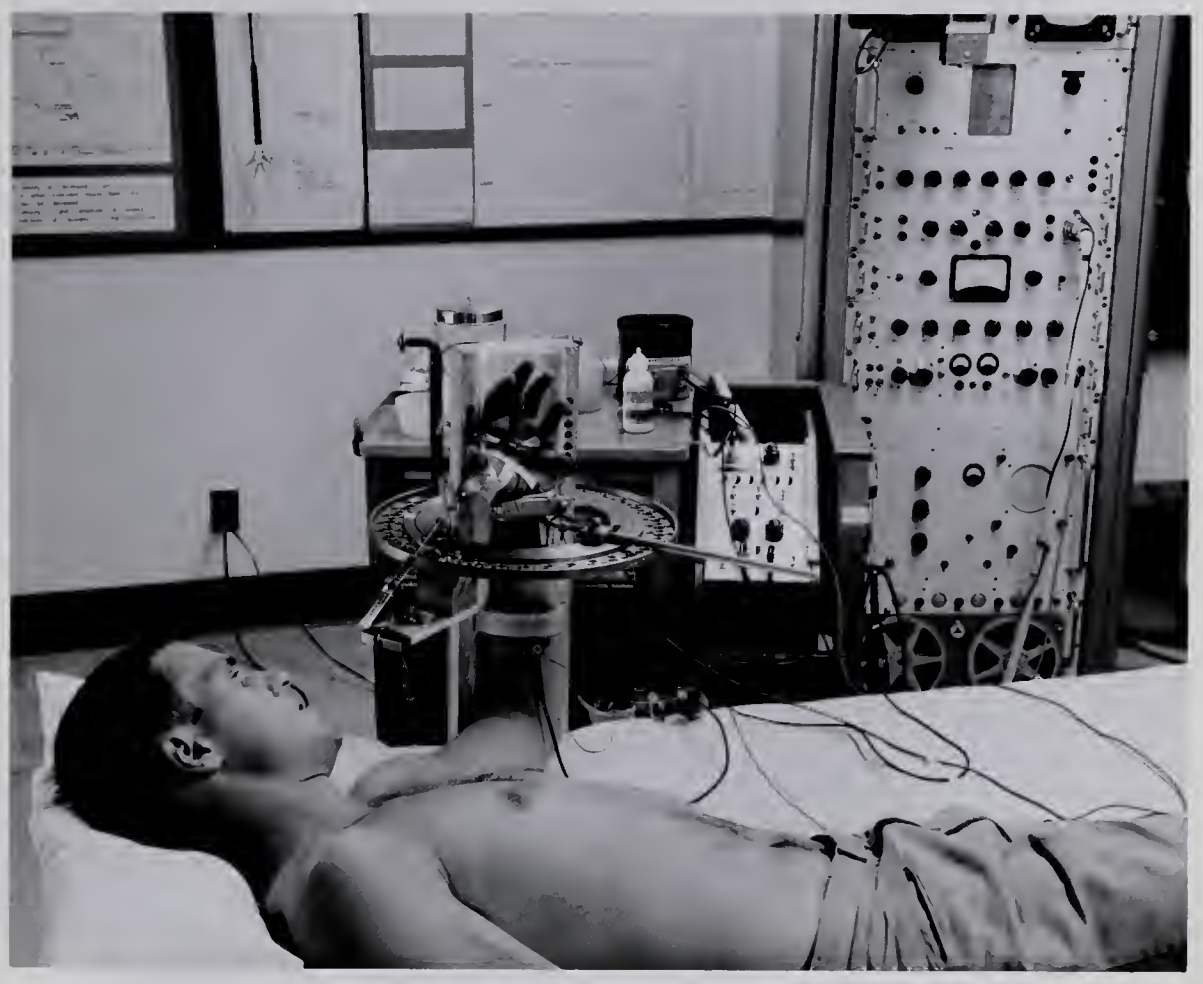

FIGURE 1: THE SUBJECT LYING SUPINE ON THE BED WITH HIS ARM STRAPPED IN THE RACE. NOTE THE STRAP AROUND THE FOREARM, THE PADDED WOODEN BAR SCREWED DOWN ON THE WRIST, AND THE HAND MOULD ACROSS THE PALM; ALL OF WHICH WERE USED TO ISOLATE THE MUSCLES UNDER INVESTIGATION.

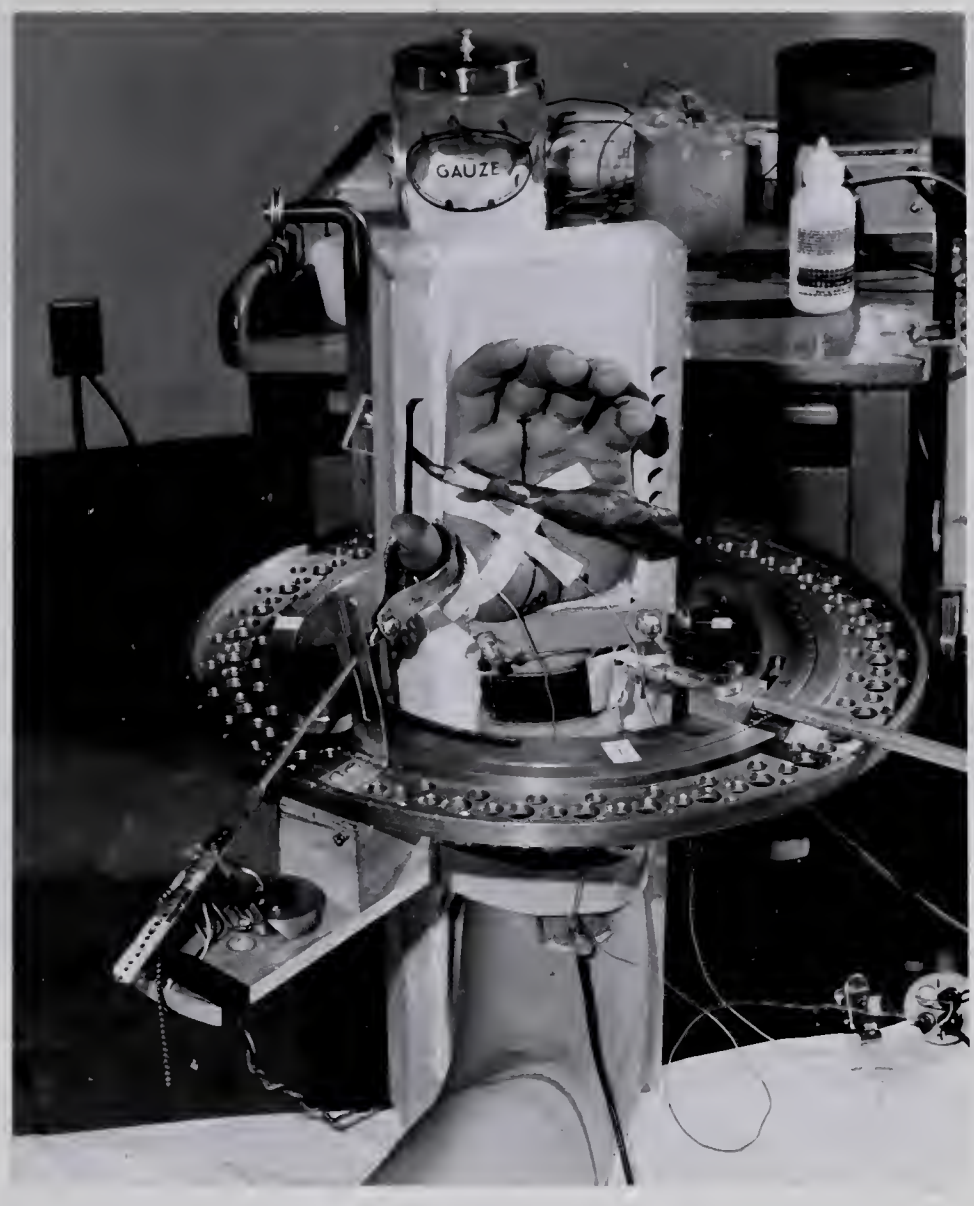

FIGURE 2: A CLOSE-UP PHOTOGRAPH SHOWING THE SUBJECT'S HAND STRAPPED IN THE RACE.

NOTE:

(1) THE PRESSURE ARM ON THE CATHODE AT THE WRIST.

(2) HOW THE THUMB IS ATTACHED TO THE MECHANO-ELECTRIC TRANSDUCER.

(3) HOW THE PLATE WHICH GOES THROUGH THE TOP OF THE TRANSDUCER IS DIVIDED EVERY FOUR HOLES BY DIFFERENT COLORS.

(4) THE E.M.G. PREAMPLIFIER TO THE RIGHT OF THE RACE.

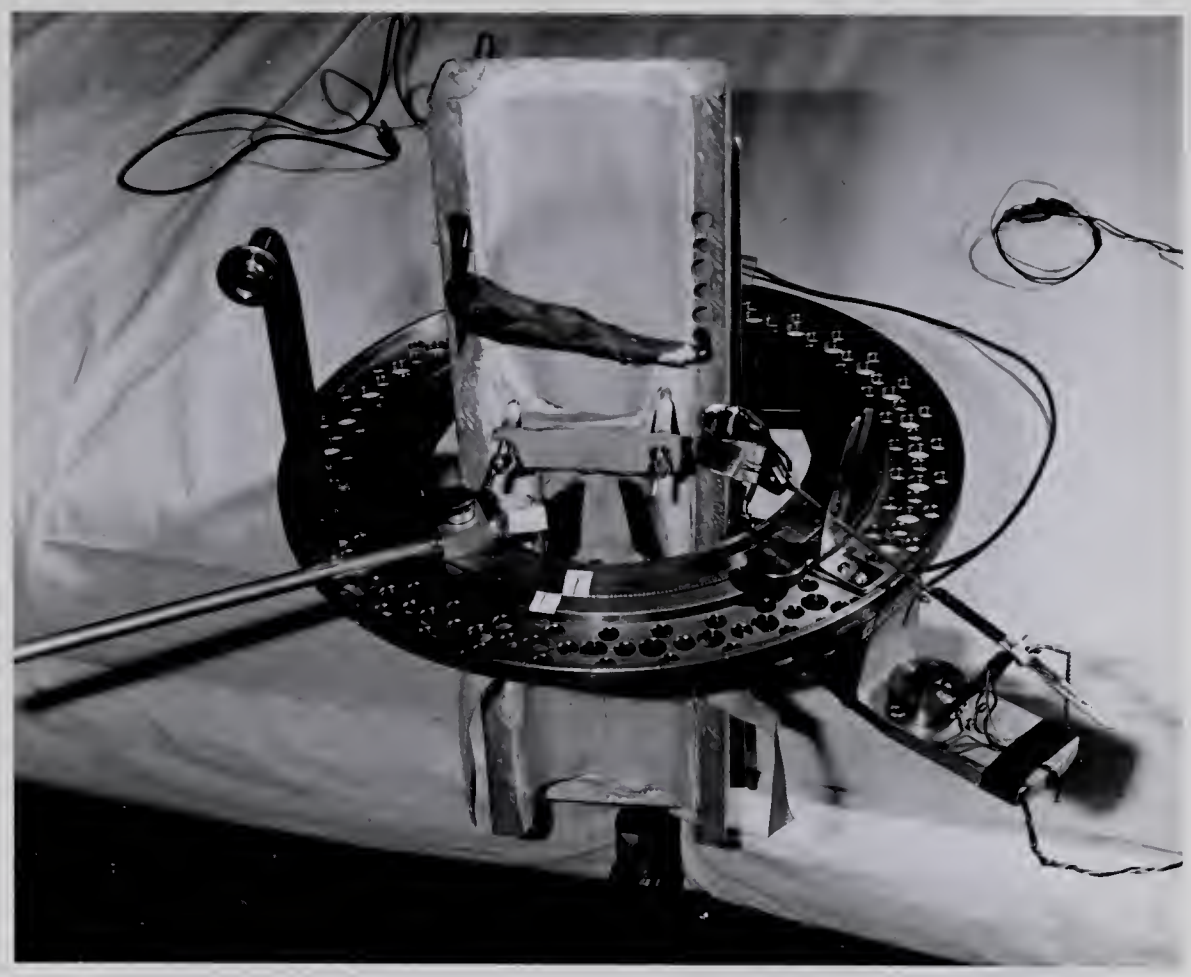

FIGURE 3: PICTURE DEPICTING THE DESIGN OF THE RACE AND CAST MOULD. NOTE:

(1) THE TWO WHITE MARKERS ON THE OUTER AND INNER PORTIONS OF THE RACE SHOWING HOW THE CIRCLE IS FREE TO MOVE AROUND THE FIXED INNER COMPONENT.

(2) THE LOWER-CENTER PART OF THE PHOTOGRAPH SHOWING THE ONE-INCH STEEL ROD, WHICH IS FIXED TO THE INNER CIRCLE OF THE RACE, IN THE SLEEVE WHICH IS WELDED TO THE BED.

(3) THE SLOT JUST BELOW THE SLEEVE THAT FITS AROUND THE THUMB. BY SIMPLY UNSCREWING THE PRESSURE IT CAN BE SWITCHED TO THE OPPOSITE SIDE.

(4) THE ANGLE OF THE FORCE TRANSDUCER. THIS ARRANGEMENT ENABLES THE SUBJECT TO APPLY TENSION TO THE TRANSDUCER AT AN ANGLE OF NINETY DEGREES.

(5) THE TWO ELECTRODES ON THE INNER SURFACE OF THE MOULD. DEPENDING ON THE ARM BEING TESTED ONE OF THESE ELECTRODES WOULD SERVE AS THE ANODE.

FIGURE 4: SHOWS THE METHOD THAT WAS USED TO CALIBRATE THE TENSION. THE MECHANO-ELECTRIC TRANSDUCER HAS BEEN TURNED SO THAT IT FACES THE LINE OF THE PULLEY. NOTE HOW THE PULLEY IS FIXED AT A HEIGHT SUCH THAT THE LINE OF PULL IS ALWAYS NINETY DEGREES TO THE TRANSDUCER.

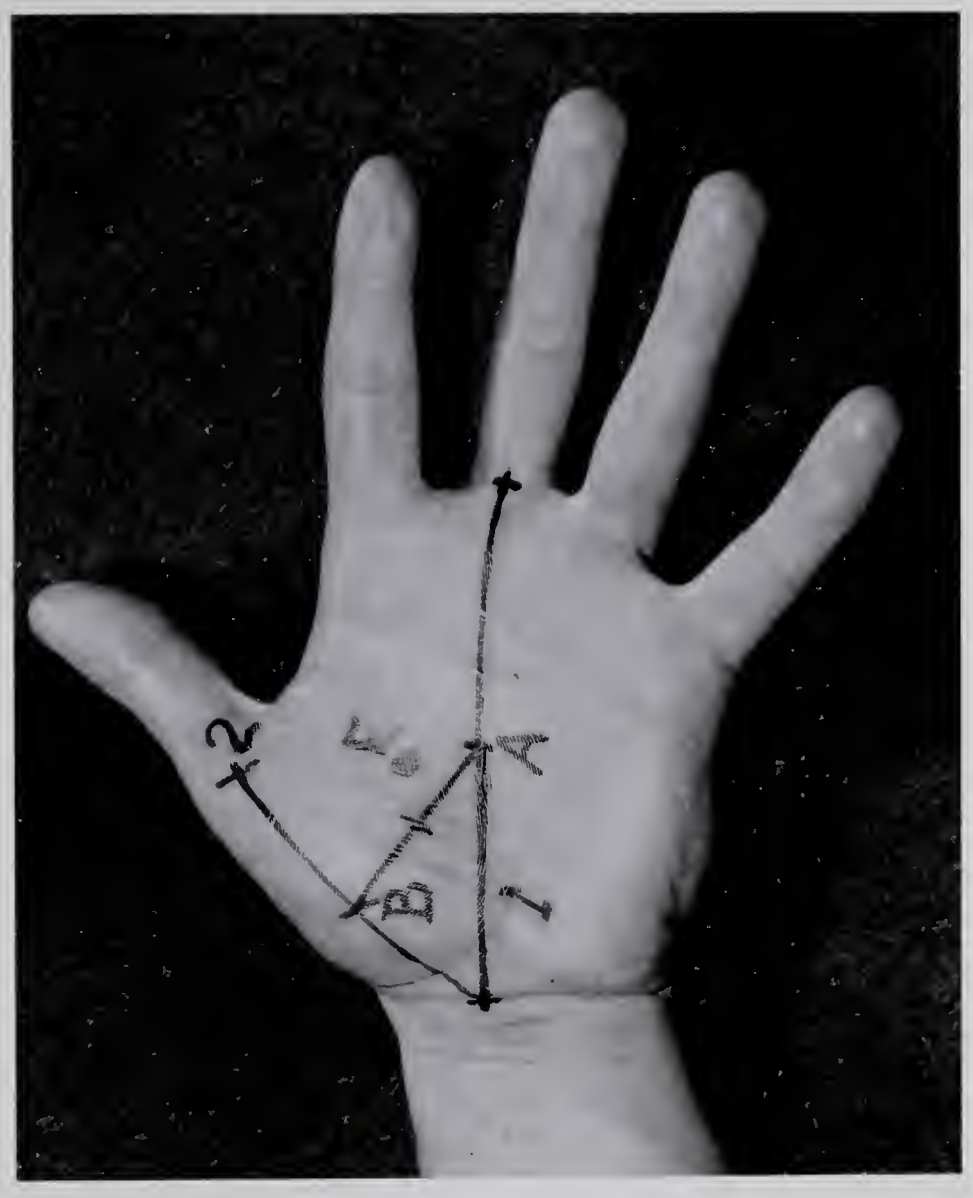

FIGURE 5: MARKING THE HAND FOR PLACEMENT OF THE RECORDING ELECTRODES.